The WELDING JOURNAL

JUNE 1952

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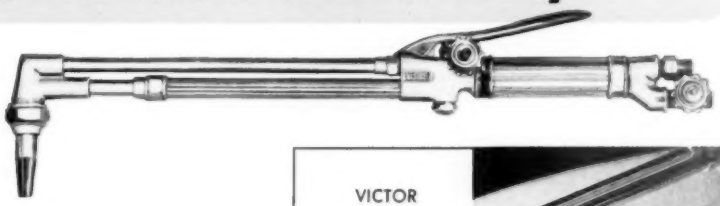

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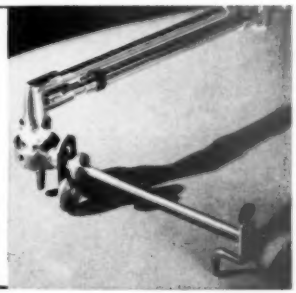

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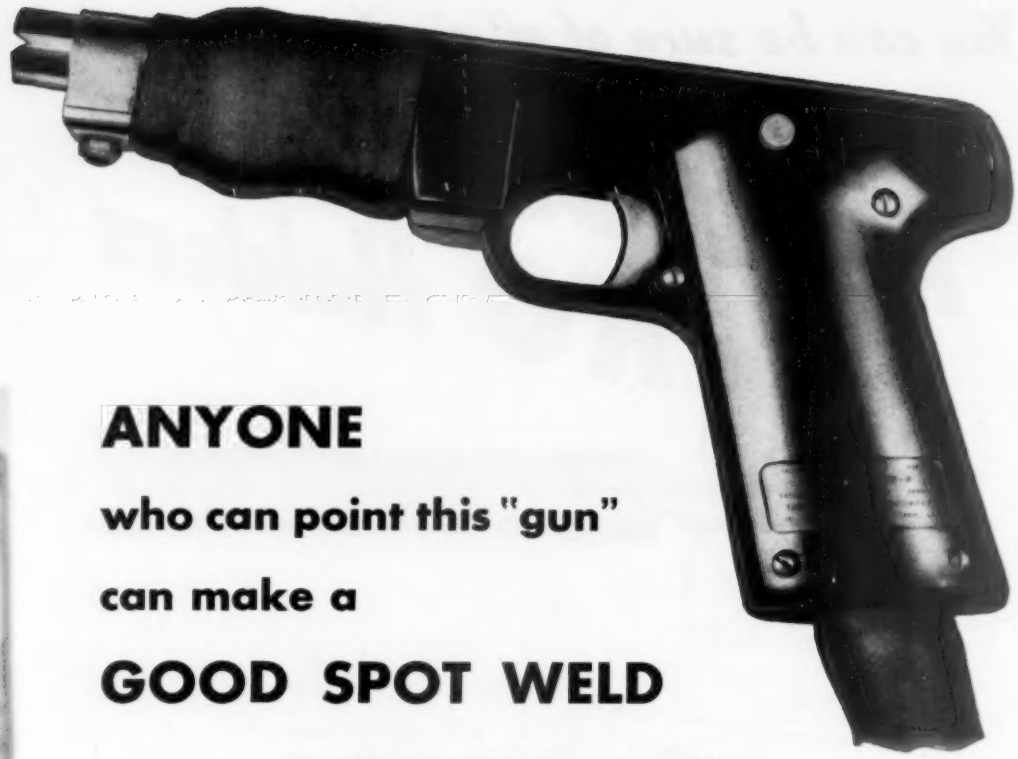

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Published for the advancement of the science and art of welding by the AMERICAN WELDING SOCIETY

Editor
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The WELDING JOURNAL

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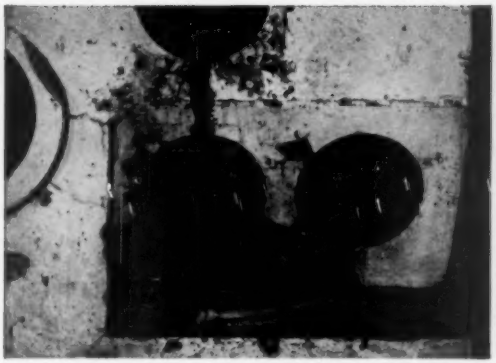

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The WELDING JOURNAL

volume 31 June 1952 number 6

Production Cutting and Flame-Hardening

Examples of cutting and flame hardening in the manufacture of mining machinery, material handling and conveying equipment

by Archer B. Jones

THE Jeffrey Mfg. Co., located at Columbus, Ohio, manufactures mining machinery, conveying and material handling equipment, coal preparation, and many other types of equipment including chain and sprockets. The oxyacetylene cutting department covers approximately 8400 sq. ft. of floor space. We consume 400,000 cu. ft. of oxygen per month supplied by a central storage unit. There are 32 men employed in the department including clerks, layout men, and control personnel. At the present time, we are working two shifts covering a period of 19 hr. per day.

It would be impossible to cover the entire range of work that passes through this department on a production basis. This paper, therefore, will cover only some of the more interesting examples of our cutting and flame-hardening.

Figure 1 shows locomotive side frames for a mine locomotive. These slabs are purchased the required width so that the only cutting necessary is for the openings and the pedestal cutouts. The rough slab is first laid off for cutting and drilling. The second operation is drilling. The cutting is done on a pantagraph machine by removing the tracing table and placing the slab the full length of the machine, covering both the cutting and tracing area. The operator then places on the side frame a thin plate which has been painted a coat of dull black, for use as a tracing table. The layoff lines are then transferred to the black plate with chalk after lining up the cutting oxygen stream with the layoff lines. The layout is then traced with a manual tracing device. Practically speaking, these frames are never exactly alike, therefore cutting cams and fixtures are hardly feasible.

Archer B. Jones, Welding Foreman, Jeffrey Mfg. Co., Columbus, Ohio.

Paper was presented before the Annual Meeting of the International Acetylene Assn., Indianapolis, Ind., Mar. 31, Apr. 1-2, 1952.

Figure 1

The round end frames which weld with the side frames to make a complete locomotive frame are shown in Fig. 2. The end frames are purchased as shown in the illustration except for the burning. As yet, we have not been able to determine a method of machine cutting these frames so at the present time they are being cut with a hand torch.

Figure 3 shows a center support bar for a coal cutting machine. These are purchased in a rough bar $2\,^{7}/_{8}$ in. thick by $9\,^{1}/_{4}$ by 138 in. long and are of S.A.E. 1055 abrasion-resisting steel. They are preheated with a charcoal fire to 400° F. The charcoal fire is built on the floor of the shop as shown in a later illustration.

These bars are located and held in place by a fixture which lines up the bar with the center line of the cutting cam and are cut using a magnetic tracing device. The operator, using a hand torch, pierces the holes necessary to start the internal cuts at the same time the machine is performing the first cut. These bars are cut on a large pantagraph machine.

The cutting machine shown in Fig. 4 is a single torch camograph which we have set up to cut vulcan chain side bars. The stock for these bars ranges from 3/4 to 4 in. in thickness and from 1 1/2 to 9 in. in width. The bar stock is placed on a roller rack to the left of the operator in order to facilitate the proper positioning of the material. Each piece of bar is initially cut off about 3/4 in. longer than the required finished length. This allows the shorter bar to fall onto a holding fixture which in turn holds the piece square for cutting. This procedure is necessary in that the bar stock is not always straight. After the short bar has been clamped in place, a radius is burned on the ends. We have two such machines set up and operating continuously.

The preheating of plates for cutting presents a considerable problem especially when there is not an abundance of floor space available. Figure 5 shows

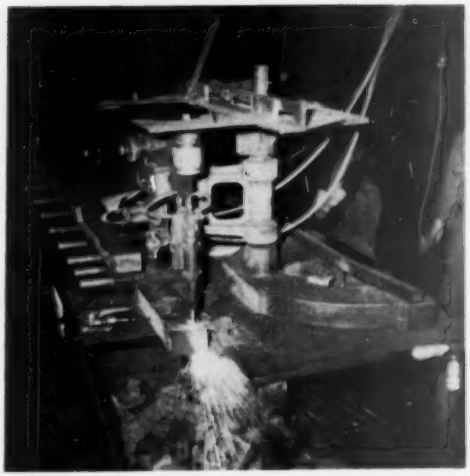

Figure 4

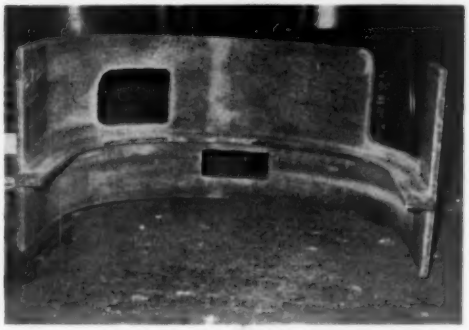

Figure 2

Figure 5

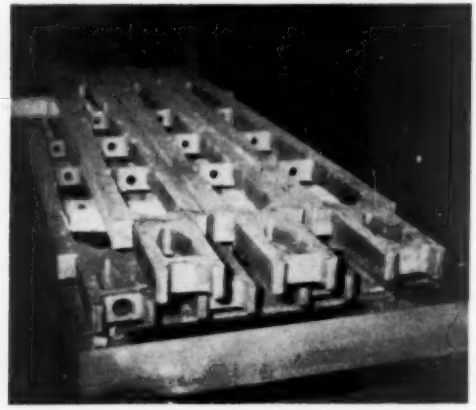

Figure 3

the preheating of No. 8750 metal plates for tank sprockets. We found it necessary to heat the plates to 400° F. prior to cutting, in that this metal is air-hardening steel. Charcoal is the medium we use for heating these plates and also other similar slabs and bars such as the 2 7/8 by 9 1/4-in. bars mentioned previously. This method is obviously undesirable in many respects. It does, however, provide some advantages due to its flexibility. The temperature of the metal is checked with "Tempilstiks" and for this particular application we find it very satisfactory. The plates shown being preheated in Fig. 5 are 1 3/8 by 30 by 120 in. and are of a size which will make four tank sprockets.

The blanks for the tank sprockets are burned four at a time as shown in Fig. 6. The blanks are being burned to the correct outside and inside diameters. The outside diameter is 27 23/32 in. plus nothing and minus 1/16 in. The inside diameter is 15 in. minus nothing and plus

$^1/_8$ in. The tolerances we are striving for are $^1/_{32}$ in. under $27^{23}/_{32}$ in. on the outside and $^1/_{16}$ in. over 15 in. on the inside. These blanks are being burned on a pantagraph cutting machine with a magnetic tracing device using a machined steel cam.

The inside diameter of the blank is used to locate the sprocket for burning the teeth, as shown in Fig. 7. Here again the sprocket is preheated with a charcoal fire to 400° F. The sprocket cutting machine shown in Fig. 7 was built by us for our own use and will accommodate a sprocket as small as 7 in. diameter and as large as 12 ft. The blank, which locates from the burned bore, is placed on the machine in a fixture. The cutting apparatus employed on this machine is a single-torch camograph which operates from a magnetic tracing device. The cams are made to cut the indentation of one tooth. The sprocket is then indexed the number of teeth required. The sprocket teeth are not cut consecutively for the purpose of limiting the amount of distortion caused by the expansion and contraction of the metal. The indexing is done with an index plate which has been machined as accurately as possible. It is manually turned and stopped with a plunger. When the sprocket is being set up, the cutting apparatus can be moved straight down the center line which permits an accurate setup. The tolerances on the teeth of these tank sprockets is plus or minus $^1/_{32}$ in. and we are maintaining this tolerance. The squareness and smoothness of the cut are shown in Fig. 8. The only work done on the tooth of the sprocket after burning,

Figure 6

Figure 8

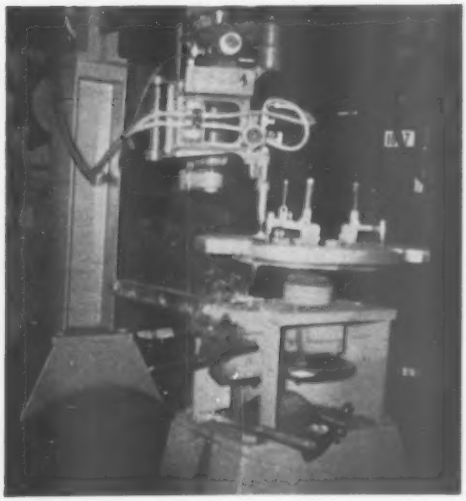

Figure 7

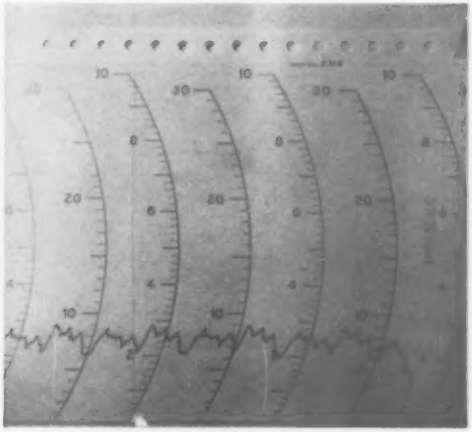

Figure 9

Figure 10

except flame-hardening, is to knock the burr from the top edge of the kerf with a pencil grinder.

The smoothness of the cut is shown by the profilometer chart in Fig. 9. The average reading, as shown on this chart, is 275 microinch finish. The specifications as stated on the drawing calls for 500 microinch finish on the tooth surface.

The machine shown in Fig. 10 is the same as the one shown in Fig. 7. In this case, however, it is set up to cut the teeth in a larger sprocket. The blank as illustrated is 2 in. thick and 49 in. in diameter. The blank was originally cut on a pantagraph machine and will have 35 teeth cut in it. This particular type of sprocket will have hubs welded to it. All subsequent operations are located from the bottom diameter of the teeth. At the present time, we have two of these sprocket cutting machines in operation. One being used for the tank sprockets and the other for our own work.

The apparatus shown in Fig. 11 is a piece of equip-

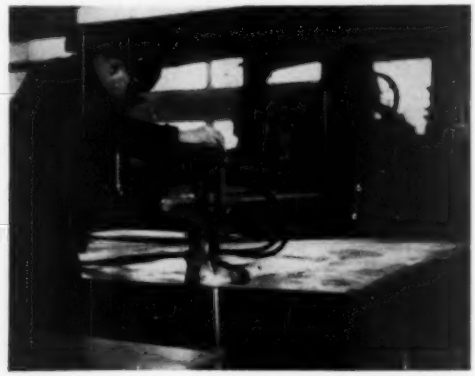

Figure 11

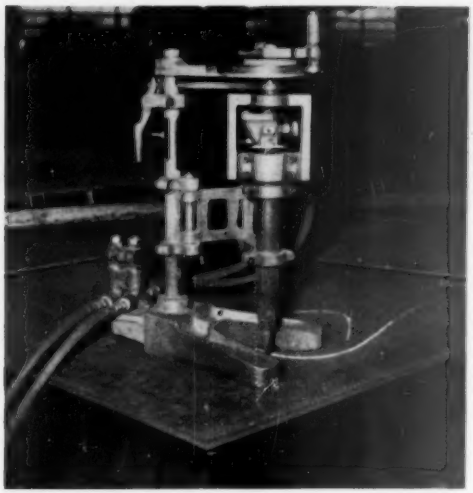

Figure 12

ment built by us for the original purpose of solving one of our fabricating problems. The reason can be attributed to the old adage, "Necessity is the mother of invention."

At our plant, we have a large number of plates to be fabricated such as the one shown in the illustration. The finished specifications of these plates require that anywhere from 6 to 40 holes be punched in them. It was our former practice to transport all of these plates from our Oxy-Acetylene Cutting Department to our Structural Department to have the holes punched. This, obviously, presented many material handling problems due to the size and bulkiness of the plates. In an effort to overcome the problems resulting from such an arrangement, a so-called "flame punch" was designed and built. This punch is used to burn the small holes that had formerly been punched. The use of this punch has saved us considerable amounts of time and expense. This apparatus weighs only 34 lb. and can be readily carried from one plate to another regardless of the location of the plates.

In addition to its original use, we are finding more and more work that the punch can be used on. The flame punch as we are using it in our plant is designed to punch more or less standard size holes such as $^{9}/_{16}$, $^{11}/_{16}$, $^{13}/_{16}$, $^{15}/_{16}$, and $1\,^{1}/_{16}$ holes. The plate thickness runs from $^{1}/_{4}$ to 1 in. The quality of the burned holes can be compared favorably with a punched hole as to size and roundness.

Figure 12 is a close-up of the flame punch. In performing an operation with the flame punch, the operator works from a center punch mark in the same manner that an operator performing the operation on a power punch press would work. The flame punch is placed on the plate with the torch approximately over the center punch mark. The operator then grasps the lever at the left rear of the apparatus and by pressing

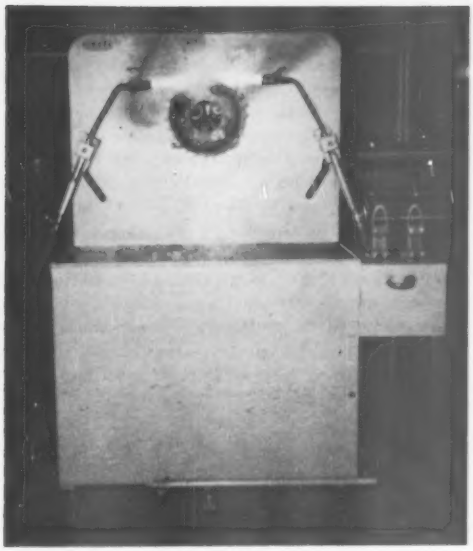

Figure 13

the lever all the way in, the torch is pulled into direct center. By turning on the high-pressure oxygen, the apparatus can be then lined up so that the oxygen stream is directly over the center mark. As the operator turns on the high pressure oxygen for piercing, he simultaneously releases the lever. This release allows the torch to move from center to the edge of the diameter to be burned. He then pulls the roller handle around the outside of the guide cam one complete turn. This action completes the operation. This apparatus is very easy to operate. Any operator who can burn with a hand torch can become very adept with the flame punch in a relatively short period of time. In addition to size, weight and other advantageous

Figure 14

Figure 15

characteristics, the fact that no electric power is necessary to operate this apparatus adds to its flexibility.

Flame-hardening in our plant varies from one piece jobs to jobs of thousands of pieces. Only a few of the larger amount jobs will be discussed here.

Figure 13 shows a spinning flame-hardening machine for finished-roller chain sprockets. All of the sprockets hardened on this machine are made of mild steel and are carburized. These sprockets also have machine finished teeth.

The sprocket is suspended on two rollers in the upper part of the bore. A knurled driver at the bottom of the bore turns the sprocket. The driver is disengaged by stepping on a foot pedal at the base of the machine. The operator, using a pair of tongs, then places the sprocket in the quench tank at the front of the machine.

The machine shown in Fig. 14 is used for flame-

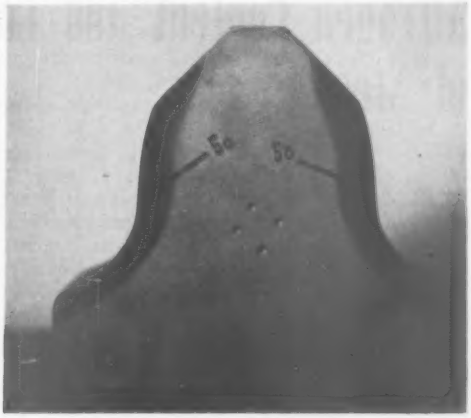

Figure 16

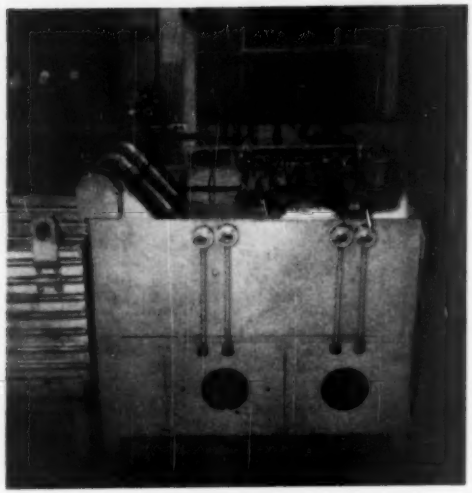

Figure 17

hardening larger sprockets not adaptable to spinning. This picture shows the flame-hardening of the tank sprocket shown being cut in Fig. 7. This is a universal machine built by us and will accommodate sprockets up to 48 in. in diameter. This machine hardens only one tooth at a time but quenches at the same time it is heating the next tooth.

Figure 15 shows a close-up of the hardening operation on the same sprocket. The heating head is at the right. In the center rear is a locating device and on the left rear is the quenching head. The hardening cycle for this particular sprocket, made of No. 8750 metal, is 80 sec. heating time; a delay of 18 sec.; and then quenching with soluble oil and water heated to 140° F. The machine is completely automatic including shutting off when the last tooth of the sprocket has been hardened. This machine operates by compressed air and electronics, has no motor, and will index any number of teeth without changing any gears. This machine, unlike most other machines of this type, does not index just the number of teeth but instead indexes distance. This distance determines the number of teeth and is changed by adjusting a micro limit switch.

The hardness pattern we are obtaining on the tank sprocket job is shown in Fig. 16. Specifications call for 50 Rockwell C at $\frac{1}{4}$ in. depth and 55 to 60 Rockwell C on the surface. We had some difficulty obtaining this hardness at the beginning without cracking the sprocket teeth. This accounts for the long heating cycle and the delay of 18 sec., before quenching. This problem also resulted in our using a soluble oil and water heated to 140° F.

We do not anticipate having this cracking trouble later on in the tank sprocket program when we get to cutting the sprockets out of No. 1345 metal. We believe we can go back to refrigerating the quench instead of heating it which was the way the flame-hardening machine was originally designed and built.

Figure 17 shows a machine we built to flame-harden the gibs and keys on our cutter chain links. These chain links travel around the cutter bar and hold the cutting bits on a coal-mining machine. This particular item is highly repetitive and the total time necessary to flame-harden each link is 42 sec. There are two keys and four gibs to be hardened on each link. These links are cast No. 4140 metal and are being air-hardened on this machine. We employ the spot method for heating the surfaces to be hardened and have the link suspended with the surface we are hardening just out of a soluble oil and water solution.

Nitrogen Content and Low-Temperature Brittleness of Steel

A RECENT investigation by the National Bureau of Standards provides valuable information on the effect of nitrogen on the brittleness of certain carbon steels at low temperatures.* Results of fracturing V-notch specimens in Charpy impact tests indicate that increased nitrogen, if present as aluminum nitride, improves the low-temperature notch-toughness—lowers the temperature at which brittleness appears—in the steels studied. But nitrogen in the form of nitrides of iron or manganese is apparently detrimental from the same standpoint. The study was conducted by G. W. Geil, N. L. Carwile and T. G. Digges of the NBS thermal metallurgy laboratory.

Various aspects of the influence of temperature on metals have been studied at NBS for a number of years. Besides its theoretical value, knowledge of the behavior of metals at low temperatures has come to have increasing practical importance. Most ferrous metals, including ordinary carbon and low-alloy steels,

* For further technical details, see "Influence of Nitrogen on the Notch Toughness at Low Temperatures of Heat-treated 0.3 percent Carbon Steel," by G. W. Geil, N. L. Carwile and T. G. Digges, *J. Research NBS*, **48** (March 1952), RP 2305.

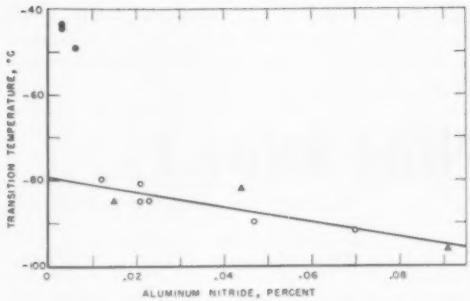

Fig. 1 The transition temperature from ductile to brittle behavior goes down as the aluminum nitride content goes up, according to a recent National Bureau of Standards study of certain 0.3% carbon, 0.2 to 0.3% silicon steels

Solid circles—1.6% manganese steels not treated with aluminum; open circles—1.6% manganese steels treated with aluminum; triangles—0.9% manganese steels treated with aluminum

tend to become brittle below certain low transition temperatures. Many steels that are satisfactory at ordinary temperatures may thus present serious fracture hazards under very cold operating conditions. Low-temperature characteristics of metals may become particularly important in aircraft operating at high altitudes or in cold climates, in military vehicles and equipment for arctic use and in refrigerating equipment.

This low-temperature increase in brittleness, or loss of toughness, is generally accompanied by a decrease in ductility, by a decrease in energy absorbed in fracturing, and by a change in appearance of the fracture surface; this surface is fibrous in appearance in higher-temperature fractures but becomes granular in fractures occurring at lower temperatures. Transition temperatures depend on many factors, including chemical composition, the manufacturing process, subsequent thermal and mechanical treatment; and method of applying stress. Even if it is not introduced intentionally, a certain amount of nitrogen normally finds its way into steel in the course of manufacture. Knowledge of the effect of nitrogen on low-temperature brittleness, as well as on other steel characteristics, therefore becomes important.

The samples studied at NBS were of 0.3% carbon steels containing 0.9 or 1.6% manganese, 0.2 to 0.3% silicon, and variable nitrogen. Included was one aluminum-treated series. Notched specimens were fractured in impact at temperatures ranging from −196 to +100° C. (−320 to +212° F.). The aluminum-treated steels tested showed much better low-temperature notch-toughness than the steels not so treated; transition temperatures, at which behavior changed from ductile to brittle, were approximately 30 to 50° C. (54 to 90° F.) lower for the aluminum-treated

Fig. 2 The National Bureau of Standards uses this Charpy type impact testing machine to measure the notched-bar impact properties of steel and other metals

The notched specimen (operator's left hand) is supported at both ends in the anvil of the testing machine, and is broken by a single blow of the pendulum (above), which strikes the specimen at its center on the side opposite the notch. After breaking the specimen the pendulum swings through between its supports. The difference between height of fall and height of rise of the pendulum gives a measure of the energy required to break the specimen

specimens. Transition temperatures ranged from about −45 or −50° C. (about −50 to −60° F.) for the nonaluminum-treated steels to about −80 or −95° C. (about −110 to −140° F.) for the aluminum-treated steels. In the latter the nitrogen was present as aluminum nitride, and transition temperatures decreased with increasing aluminum nitride content.

Reported findings by various past investigators of the effect of nitrogen content on low-temperature properties of steels have been inconsistent. Some investigators have reported decreased toughness and higher transition temperatures with increased nitrogen, while others have reported no appreciable effect. Other researchers have suggested that nitrogen may be beneficial if present in the form of aluminum nitride. The new NBS study, indicating that nitrogen is beneficial to low-temperature notch toughness if present as aluminum nitride but detrimental if in the form of other nitrides, tends to explain and reconcile the inconsistent earlier reports.

Steel Mill Maintenance Welding During a Defense Period

Organization and planning of steel mill maintenance with typical application

by R. L. Deily

INTRODUCTION

THE discussion of organization for welding presented in this paper may be held by some to be outside the scope of a nominally technical paper. In our opinion, however, some such organization is basic to the sound planning for good use of welding and its allied processes in maintenance operations of steel mills.

We have today an unpredictable period of preparation, of awareness and by making the most of it we can put ourselves in a well-organized state of readiness. So long as it is truly a defense program, we have time to build, to train and to plan. This planning must be intelligently suited to our current needs and permit fast, effective stepping up of maintenance capacity along with productive capacity to cope with any situation that can arise.

In this planning, we must not permit our enthusiasm for the welding processes to carry us away. There are limits to the processes and to the work they can do effectively. In practice, we find some management thinking of welding as a routine and secondary activity, while others consider it a panacea for every maintenance trouble in the mill. Undoubtedly, the effectiveness of management's welding organization will to a large degree determine his attitude toward welding.

In any event, the welding man favors the latter point of view—he firmly and honestly believes in his work.

Commenting on this belief, a highly esteemed engineer of a steel company once declared that "welding and burning are apt to become something of a religion or a way of life." This is a thought-provoking statement, because it is so true and untrue at the same time. It is untrue in a sense if it means that welding men do not have their feet on the ground. It is true in the sense that most of us welding people become enthusiasts about welding, and proselytize in almost a religious fashion. But why does this happen to normal engineers who by the vagaries of life become welding men?

It seems to me that the answer lies in the tremendous capabilities and contributions that each welding man sees in modern welding, and in processes such as gas cutting, inert-gas-shielded welding and so on. The more he learns about welding—what it has already made possible and what is being developed—the more limitless do the possibilities seem. There is hardly a single stage in the mining, refining and use of metals where welding does not play an important part. Ours is the age of steel, and we believe the efficient production and use of the steel depends considerably on welding.

Yet this factor is not generally realized by those not welding enthusiasts, and consequently, in our opinion the potential available in wider use of welding is not being obtained. A classic example of this lack of appreciation is listed in the December 1949 issue of *Welding Engineer* by T. B. Jefferson. An automobile executive tried to prove that welding meant nothing to the automotive industry, and backed up his opinion with the statement that there is only $13 worth of welding in a six-passenger, four-door sedan retailing at $2000. This executive was asked what the price of an unwelded automobile would be. Since the plant had never tried to build the sedan unwelded, there wasn't any accurate answer to the cost. However, his best estimate was that the auto might be priced at least $1000 more *if there were no welding.*

WELDING IN STEEL MILL MAINTENANCE

It would be impossible to estimate the cost savings brought about by the use of welding and allied processes in the production of steel, particularly since steel itself is such a complex product. Where concrete data are given in the literature, the savings indicated are substantial. For instance, Fey,* in describing

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Paper was presented before the Thirty-Second Annual Meeting, AWS, Detroit, Mich., week of Oct. 15, 1951.

* Fey, R. F., "Builds Welded Blast Furnace in Eight Months." *Steel*, 113, 114–150, 320 (1943).

construction of a welded blast furnace in 1943, indicates that a riveted furnace would have cost 50% more than a welded furnace. He also estimated that there would be a 5% per year saving in operation due to less maintenance, easier maintenance and so on.

Returning to the comments of that steel plant engineer, he says further that welding and burning are subsidiary to the *general problems* of maintenance, with which we heartily agree. These are:

I. Keep equipment running at all times.
II. Keep equipment running at lowest cost.

In order to accomplish these aims, the maintenance departments are divided into mechanical, electrical and service groups, in the customary steel mill organization setup.

The mechanical group uses machine tools, either portable or stationary, and uses the kind of skills which traditionally go with machine shops.

The electrical group has to do with electric motors (including their mechanical phases) and all the appurtenances usually associated with electricity.

The service groups generally are the crafts, including carpenters, riggers (or bridgeman), painters, bricklayers, welders, burners and unclassified labor; these groups use tools peculiar to their crafts.

Thinking about maintenance problems in such broad outlines makes it obvious that welding and burning, as crafts, are indeed subsidiary, and this is undoubtedly the viewpoint of the steel plant engineer previously mentioned. Yet, actually, the welding operations as a whole are so basic that they will be found essential to most other types of maintenance. It may be fairly stated that most of the important types of maintenance could not be conducted under current conditions without welding.

In line with the above maintenance groupings, the usual organization in a steel mill consists of an over-all superintendent, generally a master mechanic. Reporting to him as direct assistants are a mechanical and an electrical man who divide between them the responsibilities indicated by their titles. Welding has come into the organization and is generally covered by a welding foreman, sometimes in the electrical, more often in the mechanical, setup. However, we propose that there should be a welding assistant reporting to the master mechanic on an equal status with the mechanical and electrical assistants.

This welding assistant and his organization will be able to coordinate all the various activities in the domain of welding as they affect the steel mill. That knowledge of welding is a full-time job for capable personnel is indicated by the 1579 closely printed pages of welding information in the current 1950 edition of the *Welding Handbook*. This information, so far as it affects steel mill maintenance, can be summarized as follows:

Typical Welding and Burning Operations in Steel Mills

A. Use of oxygen by itself.
  1. Lancing.
B. Oxyfuel gas-flame cutting processes.
  1. Manual cutting.
  2. Machine cutting.
  3. Oxygen machining.
    (*a*) Scarfing.
    (*b*) Gouging.
    (*c*) Edge preparation.
C. Welding processes.
  1. Oxyacetylene welding.
    (*a*) Fusion welding.
    (*b*) Braze welding.
  2. Thermit welding.
  3. Arc welding.
    (*a*) Carbon arc.
    (*b*) Bare metal arc.
    (*c*) Shielded metal arc.
    (*d*) Atomic hydrogen.
    (*e*) Inert gas shielded.
    (*f*) Automatic welding.
  4. Resistance welding.

To briefly consider welding processes, we will start with oxyacetylene welding, since this was the first process to be used on a wide scale. It would be a mistake to say that oxyacetylene welding has not changed at all since 1900, but this is nearly true. Equipment has been refined and made more flexible, but basically gas fusion welding (and braze welding) is done now as it was years ago. It is an indispensable tool used year after year in steel mill maintenance particularly for cast-iron welding and for small pipe fabrication.

By using an extra line for introducing pure oxygen, the oxyacetylene welding torch was very early modified to become a cutting torch, which resulted in tremendous broadening of the welding industry. Such oxyacetylene cutting torches have been developed into numerous variations for special jobs in the steel mills, as well as being mechanized by mounting on a motor-driven carriage. One of the specialized oxyacetylene torches is the scarfing torch; the scarfing operation because of its close integration with steel production, and its high consumption of oxygen and fuel gas, has further pointed up the need of a welding organization in the steel mills.

For example, a steel mill without a specific welding organization was having trouble with scarfing torches. The service company was called to assist in ironing out the difficulties, and a meeting of all interested parties was held. This meeting included the mechanical maintenance group, who had charge of repairing torches; the slab mill superintendent and foreman, in whose department the torches were being used; the combustion department who were responsible for the oxyacetylene pipelines; the safety department who are involved as a matter of course in steel mills; and, finally, the outside welding service group who were advising what might be done.

The mere statement of the situation shows the difficulties that arise where there is no specific welding organization. Each one of the individuals in the meet-

ing was a capable person, but his primary interest was in something other than the welding problem. Yet, the successful operation of the slabbing mill, under current conditions, is highly dependent on the scarfing operation. The outside welding service is anxious to help, but from an organization standpoint can only advise each department, in a sense, separately and so the job goes along haltingly, in spite of the best intentions of everyone. It is the old story that what is everybody's business is nobody's business.

Because steel mill equipment is subject to such severe wear and tear, the maintenance organization has the twin problems of build-up and patch-up to solve. For this work the arc-welding processes are the most widely used; they are also, surprisingly enough, at the same time the oldest and the newest of autogenous welding operations. It might fairly be said that widespread use of the versatile coated electrodes for steel mill welding has occurred only since about 1930. As a matter of contrast, we find shop welding with carbon arc described in La Lumiere Electrique of 1887! These early French welders were making barrels and pipes and except for battery source of power, worked under surprisingly modern shop conditions. Needless to say, the carbon-arc process is still of importance to the steel industry for certain very special jobs.

The most recent electric arc welding development is the inert-gas-shielded process of which there are two types; the nonconsumable tungsten electrode with or without added filler metal and the most recent type which feeds a consumable electrode through the arc (Aircomatic*). These welding processes have already revolutionized the welding of almost all nonferrous metals, particularly aluminum, nickel and copper alloys as well as the higher alloy steels such as stainless. Since the steel mill maintenance man is confronted with numerous nonferrous welding problems such as Diesel engine pistons, tuyères, mill guides and so on, these inert arc processes are of particular interest. In addition, with the Aircomatic process applied by means of an automatic welding head, all of these materials can be welded and overlaid automatically. The scope of tools available to steel mill welding engineers has been appreciably widened by this development.

This very brief listing of the types of welding and burning operations used in steel plants, both in maintenance and in production suggests how welding cuts squarely across all steel mill operations. This, combined with the diversity of the welding operations, makes "welding" for the steel man a complex subject, requiring constant study. Furthermore, this wide usefulness and complexity of subject is the basic reason why welding and burning become a way of life.

For a steel mill to get what it should from welding and allied processes, an organization must be set up for that particular purpose. This welding organization is charged with the responsibility of keeping abreast of welding developments, and of applying those developments throughout the operations of the steel plant. It is hardly necessary to point out to an audience of welding men that this keeping abreast of developments is no easy task, and is indeed a full-time job for enthusiastic personnel. What it amounts to for a divided, scattered, miscellaneous staff of welding foremen is sheer impossibility. Even if this were not the case, the division of authority for lack of organization is a fatal blow to successful application of welding in the mill.

In addition to its regular welding activities for maintenance the welding organization will be able to offer assistance to those steel mill departments using oxygen in metallurgical ways, such as for decarburization, flame hot topping and so on. The welding man's knowledge of oxygen pipe lines, oxygen flows, regulating equipment, etc., will be invaluable to the blast furnace, open hearths or other departments concerned with the use of metallurgical oxygen. Some idea of the magnitude of welding operations in the steel mills can be obtained from a look at the oxygen-consumption figures for the steel industry. We find that the industry used an estimated 9 billion cubic feet of 99.5% oxygen in 1950, and that the consumption per ingot ton increased from an estimated 40 cu. ft. in 1940 to 90 cu. ft. in 1950.

It has been brought to our attention that such a welding organization, set up for the positive promotion of all the numerous welding processes mentioned, will also have an advisory job of great value. This job is the prevention of misapplications of welding techniques or processes. Some of these are more or less obvious such as unnecessary burning of foundation bolts, or welding on highly alloyed steels without proper precautions. Other misapplications are more subtle, and involve uneconomic fabrication or reclamation by welding, or involve repair welding to the point where fatigue failures turn gains into losses. Obviously, however, such recommendations cannot be made unless there is in the steel mill setup, "This welding organization . . . charged with the responsibility of keeping abreast of welding developments, and of applying these developments throughout the operations of the steel plant."

* Trademark registered U. S. Patent Office.

Characteristics of Submerged Arc Welding with Three-Phase Power

Submerged melt welding operating with three-phase welding power applied to two welding rods arranged in close tandem so as to deposit weld metal into a common welding pool offers many advantages in some applications over other methods of submerged arc welding

by E. A. Clapp and N. G. Schreiner

THE choice of the type of power to be used for welding is usually a compromise between two major factors. The use of alternating current, in most instances, satisfactorily eliminates the effect of magnetic fields around the arc, usually known as "arc blow." Such welding current is almost universally supplied by specially designed single phase transformers, and in a shop where a significant amount of the total power consumption is represented by a welding load, a considerable unbalance in the usual three-phase plant supply system may occur. Balanced loads can be obtained with motor-driven generators; with the motor being operated from the three-phase line, and the generators usually providing d. c. welding power. This type of power, however, is particularly susceptible to arc blow, the correction of which may prove to be practically impossible in many instances. A few alternating current generators have been installed, but have not been particularly successful, chiefly because of lack of flexibility in control of the welding power.

It is obvious that there would be considerable advantage to be gained through the use of three-phase power directly for welding. Proper choice of transformers, corrective capacitance, and adjustment of welding load should provide an essentially balanced primary load and yet retain the virtues of an a. c. welding source as compared with d. c.

One method that we have devised for accomplishing such a result involves the use of the automatic submerged melt process using two rods positioned in tandem over the seam to be welded. Each rod is independently driven by rod-feed motor, control and guide tube. One lead of the three-phase power supply is connected to each rod, and the third lead to the ground clamp. Our new technique has now been developed to the point where it is being used quite extensively in commercial practice, especially for the manufacture of tubular products on a high-production basis. The method has proved to be particularly economical. Welding speeds obtainable are two to three times faster than can be realized with a single-rod technique.

In the initial development of this technique, the three basic three-phase transformer circuits; that is, open- and closed-delta and wye, were investigated. It was found that all three circuits could be utilized for welding but that the two delta circuits exhibited considerable advantage over the wye circuit. One of the primary advantages is the fact that the welding current which can be drawn from a closed-delta system is 1.73 times the rated capacity of the transformers, whereas only the normal rated capacity can be used in the wye system. The high voltage produced by the wye system is of no advantage as the excess must be absorbed by appropriate ballast. As it is current that generates the welding heat, the effectiveness of the delta system is obviously considerably greater. It is the two modifications of this circuit that have been utilized commercially.

There were many factors to be investigated in addition to those normally applicable to the single-rod technique. Among these factors are the possible effect of phase angle, phase sequence, power distribution between rods, and the effect of primary power factor. As the investigation progressed, it was found that most of these factors had considerable influence on the quality of the welds produced. It is these effects, and the control of weld quality that is provided by their proper utilization, that impart to the three-phase tandem technique a uniqueness heretofore unknown in the realm of welding. The effects of each of these variables will be described independently, and then an explanation given for their combined influence. Some reference will be made to a d. c. system, as this will help to clarify the a. c. phenomena.

As is well known, a flexible or movable conductor can be set in motion by the action of a magnetic field. An arc is a flexible conductor and therefore subject to deflection by a magnetic field. In submerged melt welding, weld quality and the direction of arc movement or deflection are definitely related. If the arc is deflected rearwardly over the weld puddle, a weld of poor appearance will be produced; forward deflection will result in production of smooth, undercut-free welds.

The magnetic field required to produce the desired arc deflection can be obtained in several ways: by permanent magnets, electromagnets, or self-induced field. The simplest method, however, both from the standpoint of control and economy, is the use of the field surrounding a second conductor; that is, by using two electrodes in tandem.

If the magnetic pattern of such a system is considered, it will be shown that by proper choice of electrode polarities, the fields of the leading rod current and the total ground current can be utilized to deflect the arc at the trailing rod in the forward direction, thus favoring production of a good weld. At the leading rod, the fields produced by the trailing rod current and of the ground current of the leading rod tend to neutralize. Thus, the direction of deflection of the leading arc is not subject to such accurate control. How-

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ever, as long as all magnetic conditions are so established and controlled as to deflect the trailing arc in a forward direction, welds of acceptable quality can be obtained. The deflection of the leading arc is relatively unimportant.

The direction of welding with respect to the location on the work of the ground line contact is also important and is an integral part of the magnetic pattern mentioned above. It is usually recommended that welding proceed in a direction away from the ground contact, and in general this practice is advocated when the three-phase connection is used. However, because of the facility with which the ground as well as the rod currents can be adjusted in the three-phase connection, suitable conditions can be established for welding toward the ground contact.

PHASE ANGLE

The phase angle between the two a. c. electrode currents was found to be of considerable importance and to have a direct bearing upon weld quality. The phase angle relationship of these two currents regulates the time periods during which the two electrodes are of similar or dissimilar polarities. As was pointed out above, the polarities of the electrodes are a major factor in determining arc deflections. When welding with a.c., the values of the various induced fields are constantly varying in intensity, and therefore the arc deflections will not be constant but also will vary. The relative times of deflection in the forward and rearward directions, particularly of the trailing arc, might be expected to exert considerable influence over the weld quality.

The ground current is also of importance magnetically. In the three-phase system, the ground current can be varied over a wide range, independently of the currents introduced into the welding rods. On the other hand, in the connections used with d.c. or the combination of d.c. and a.c. on tandem arcs, the ground current is not subject to such exact control. By varying the ground current, two factors are brought under control: one, the effect of the induced field due to the ground current, and second, the polarity time factors of the two electrodes. This is because changing ground current will alter the phase angle relationships of the the three currents.

PHASE SEQUENCE

Another factor found to be of great importance was phase sequence. With the open-delta circuit (which normally provides rather high ground current) and with a welding direction away from the ground contact on the workpiece, it was found that to produce good quality welds, welding currents had to be in "reversed" phase sequence, the order being ground, trail rod, lead rod. With the closed-delta circuit (with ground current

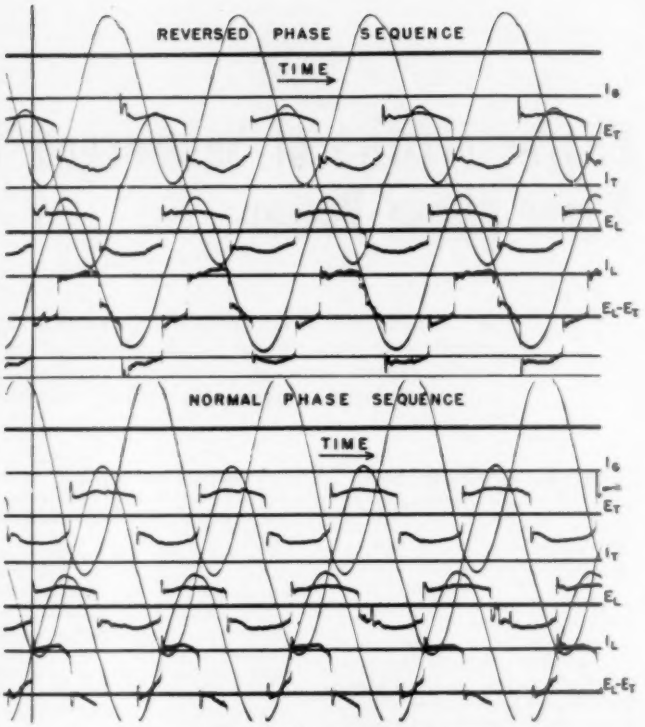

Fig. 1 Oscillograph of closed-delta circuit

Upper Group No. 55—reversed phase sequence—poor weld. Lower Group No. 52—Normal phase sequence—good weld.
Legend: I_G—ground current; I_T—trail rod current; I_L—lead rod current; E_T—trail rod voltage; E_L—lead rod voltage; $E_L - E_T$—voltage between rods

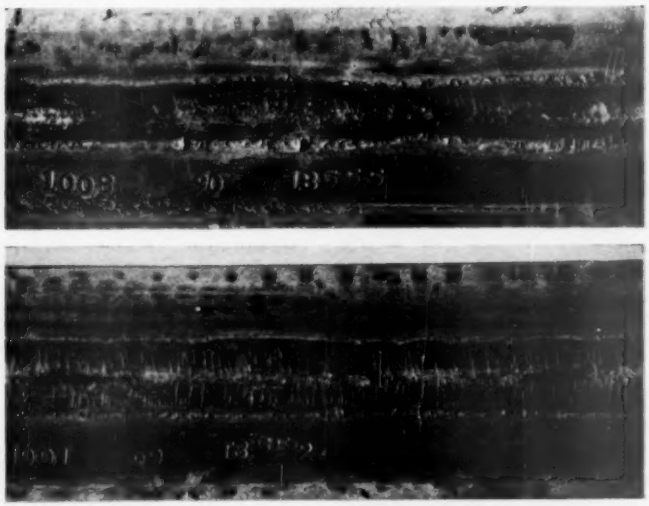

Fig. 2 Typical welds in $^1/_4$-in. plate—closed-delta circuit

Upper weld illustrates reversed phase sequence. Lower weld illustrates normal phase sequence. Refer to oscillographs Nos. 55 and 52 of Fig. 1

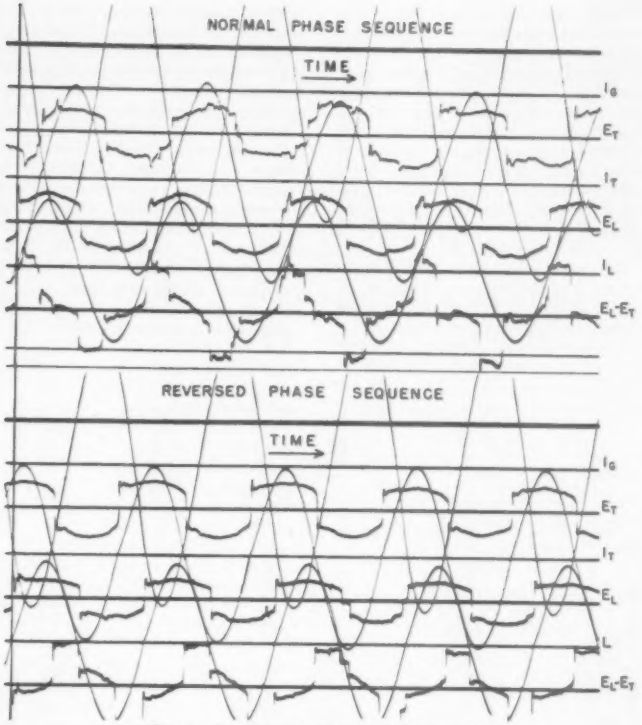

Fig. 3 Oscillograph of open-delta circuit

Upper Group No. 37—normal phase sequence—poor weld. Lower Group No. 49—reversed phase sequence—good weld. Legend: same as Fig. 1

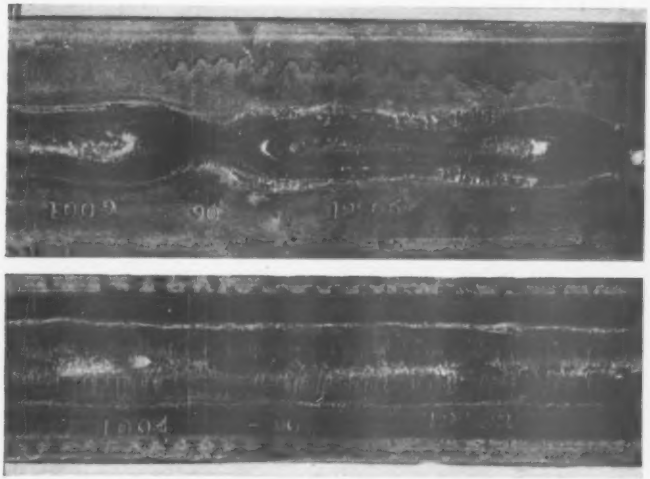

Fig. 4 Typical welds in $^1/_4$-in. plate—open-delta circuit

Upper weld illustrates normal phase sequence. Lower weld illustrates reversed phase sequence. Refer to oscillographs Nos. 37 and 49 of Fig. 2

only slightly higher than rod currents) and with direction of welding away from the ground connection, a "normal" phase sequence—lead rod, trail rod, ground—was necessary to produce satisfactory welds.

When an inductor was inserted in the ground line of the open-delta system, thus reducing the ground current to the level normally employed with the closed-delta system, unsatisfactory welds resulted unless the phase sequence was changed from reverse to normal. Conversely, removal of the ground line inductor from the closed-delta system, thus increasing the ground current, produced unsatisfactory welds with the normal sequence.

An examination of the oscillograms shown in Figs. 1 and 3 will indicate not only the variation in the polarity time factors due to the change in ground current, but also the variation in these factors due to the change in phase sequence. Fig. 2 shows the welds that are obtained with the values of Fig. 1 while Fig. 4 shows the welds produced by the values recorded in Fig. 3.

POWER DISTRIBUTION

The distribution of power between rods was found to be of great importance at high speeds of welding. Under the conditions of testing, it was found that, in general, best results were obtained when 40 to 50 per cent of the total power input at the weld zone was introduced through the leading rod. It was also found desirable that the leading rod carry less current than the trailing rod and that the ground current be greatest of the three. This was true with all three basic circuits. The total power input to the weld is the sum of the power for each arc. The power input to each arc can be approximated quite closely by multiplying each arc current by its corresponding arc voltage.

Magnetic enviroment at the welding zone is dependent not only upon the welding currents but also upon the proximity of magnetic material in jigs and fixtures. Therefore, it was reasonable to predict that the weld quality would be affected by the variations in the mass of adjacent magnetic material, and that the above distribution of power might not apply. This prediction was borne out in the practical application of the circuit. The power was divided between the two rods by adjustment of currents and voltages so as to produce the desired weld under the jigging conditions at hand.

POWER FACTOR

Tests were run both without any primary factor correction and with full correction. Changes in primary power factor had no discernible effect upon weld quality. There was, of course, considerable effect upon primary line and phase currents,

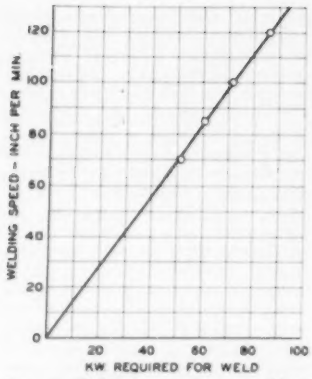

Fig. 5 Welding speed vs. welding power for $^1/_4$-in. plate

and ample corrective capacitance is to be recommended in order to keep the phase currents within the rated values for the primary supply transformers used. Power factor correction can also be used to bring the primary load close to balanced conditions.

EFFICIENCY OF POWER UTILIZATION

The efficiency of power utilization in all submerged arc welding is improved by increasing the welding speed above the values considered normal for single-rod techniques. Eventually, however, a range is reached in which further increases in speed produce little or no change in efficiency. The speeds attained by the tandem technique, being two to three times greater than single-rod techniques, are apparently within that range. Tests on $^1/_4$-in. plate over the speed range of 70 to 120 in. per min. showed that the relationship existing between speed and actual welding power is essentially straight-line. See Fig. 5.

The energy required to make one foot of weld is about the same for both tandem and single-rod techniques when welding thin plates. However, efficiency of the tandem process, as compared with the single-rod technique, rapidly increases as the plate thickness is increased, until, when welding 2-in. plate, the tandem process requires only 75 per cent of the energy required by the older method. This is illustrated in Fig. 6.

The ratio between the weld size (or nugget area) and the energy input to the weld was found to be a constant over the range of 14-gage to 2-in. plate with a welding speed range of 190 to 17 in. per minute. This is shown graphically in Fig. 7.

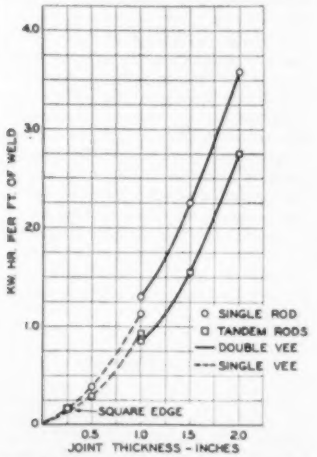

Fig. 6 Comparison of energy requirements for single rod and tandem rod techniques

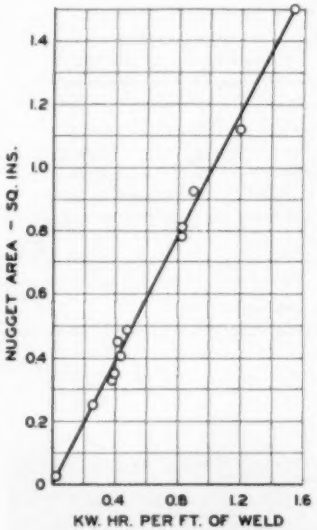

Fig. 7 Relation of energy input and cross-section area of weld nugget

THEORY OF THREE-PHASE OPERATION

As a result of the above observations, it was deduced that complex magnetic forces were responsible for the variety of results obtained during the tests. An hypothesis was developed which attempted to explain the relationships between weld quality and current maguitudes, phase angles, phase sequence, and welding direction (with respect to the ground connection) in terms of the magnetic pattern created at the welding zone. Subsequent experiments, as will be described, showed that the essential details of the theory were correct.

At any given instant, the magnetic relationships resulting from the use of d.c. power should be applicable to an a.c. system. In an a.c. system, however, the pattern of the relationships is constantly changing. Since there are intervals when the electrodes will be of the same polarity and others when they will be of opposite polarity, there will exist, alternately, conditions tending to produce good and poor quality welds. The ratio of the times of existence of the two conditions is a function of phase angle between the two electrode currents. Thus, alteration of the phase angle should change the magnetic condition from predominantly "bad" to predominantly "good," or vice versa.

In the d.c. system the ground current is the arithmetical sum of the two electrode currents and is not susceptible to independent control. In the three-phase system, however, this current is the vector sum of the electrode currents and it can be varied independently. The ground current also produces a magnetic field that exerts considerable force upon the arcs. In the three-phase alternating current system, this influence is brought under control. Thus, regulation of the ground current should simultaneously control the effects of the induced fields of the three currents by changing the intensity of the field associated with the ground current and adjusting the phase angle between the electrode currents, and thus the "time" factor described above.

These deductions lead to the conclusion that, in order to obtain a high quality weld, the time period during which the trailing arc is deflected in advance of the completed weld must be longer than the time period of rearward deflection. If this tentative conclusion is assumed to be correct, the effect of phase sequence might readily be explained. It was reasoned that if all factors relating to the time factor were not changed, changing phase sequence could only alter the sequence of events at the welding zone, and in effect, would rotate the arc deflection pattern around a vertical axis located between the two electrodes. Thus, under conditions producing predominantly forward arc deflection with a given phase sequence, the same conditions would produce a predominantly rearward deflection when the phase sequence was reversed, with corresponding change in weld quality.

In considering the effect obtained when the direction of welding with respect to the ground contact point is changed, the explanation of the action in the d.c. system might be expected to apply at any given instant. However, this concept must be modified. The ground current of the arc farthest from the ground contact point is in phase with the arc current, but the ground current at the arc nearest ground, being the vector sum of the two arc currents, *is not in phase* with the second arc current. Therefore, the ground current does not influence the two arcs to the same degree nor at the same time.

Reversing the direction of welding,

therefore, might be expected not merely to reverse the pattern of arc deflection at the two electrodes, but in addition, probably would alter the time factor of arc deflection! If the d.c. explanation applied directly, it would be expected that the effect obtained by reversing welding direction could be compensated by a reversal of phase sequence. Yet, if the second explanation is correct, this should not be effective, and it might rather be expected that the magnitude of the ground current should be altered, thus changing both the strength of its induced field and the time factor controlled by the phase angle between the two electrode currents.

In combining the above considerations, it became obvious that although the angle of deflection of the trailing arc *vs.* time would be the resultant of the four essentially sine wave functions, and therefore should follow a general sine pattern, in effect, the zero axis of the deflection curve would be shifted from the normal position. Therefore the time factor would not be predictable as a function of phase angles and sequences alone. Because of the practical difficulty either of measuring intensity and direction of the magnetic fields or of calculating these quantities (the current path and distribution within the workpiece is not readily determinable), the relationship between optimum ground current magnitude and welding direction could not be predicted.

EXPERIMENTAL CORROBORATION OF THEORY

Although the above theory was based, to a limited extent, upon observed phenomena, most of it was developed without benefit of supporting evidence. It was desirable that such evidence be obtained, if possible, because successful commercial application of the technique would require a dependable working theory for guidance of service personnel.

Welds could be and were made under a variety of conditions to show the effects on weld quality, but these could not display the mechanism by which the results were produced. In order to study the arc action directly (the arc normally being completely blanketed from view by the granular Unionmelt welding composition), test welds were made under a partial atmosphere of argon to prevent oxidation effects. These welds were made at current and voltage values equal to those used with the Unionmelt welding composition, and the arcs photographed with a hyperslow motion technique. Film speeds were chosen to provide approximately 6000 frames per second—100 frames per cycle.

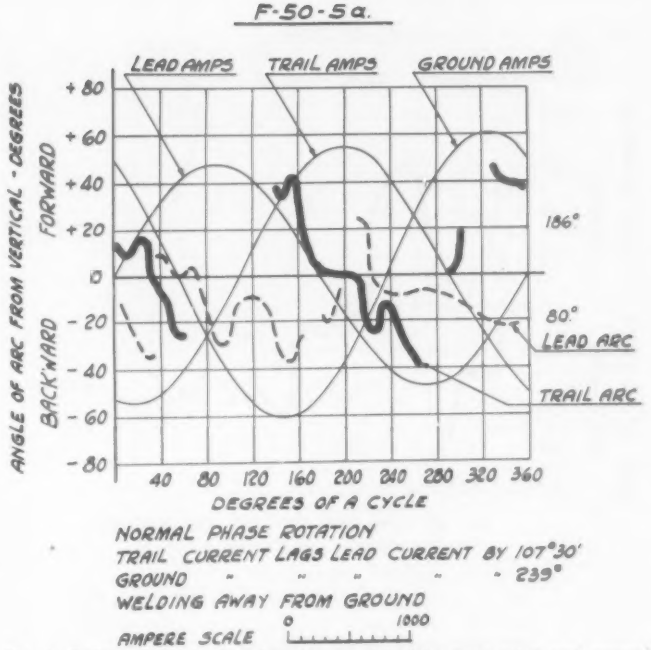

Fig. 8 Deflections of lead and trail arcs with delta connection and normal ground current

Current—lead rod, 920 amp.; trail rod, 1040 amp.; ground, 1160 amp.

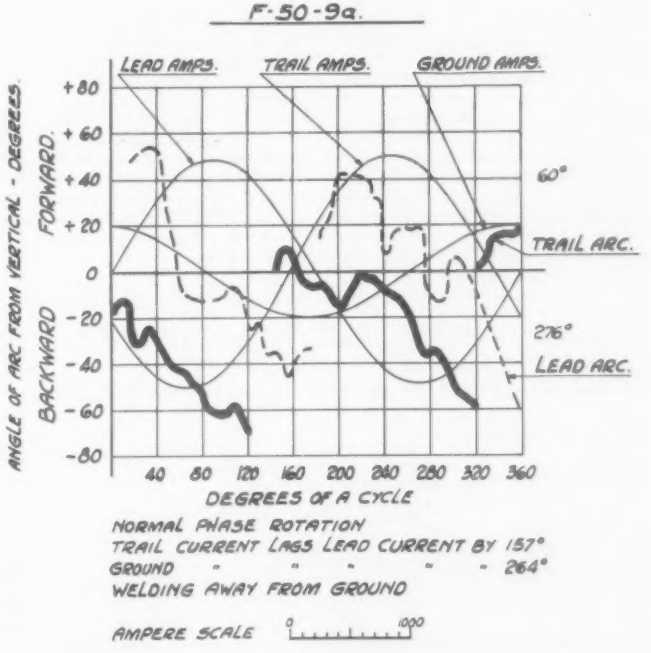

Fig. 9 Deflections of lead and trail arcs with delta connection and low ground current

Currents—lead rod, 920 amp.; trail rod, 960 amp.; ground, 380 amp.

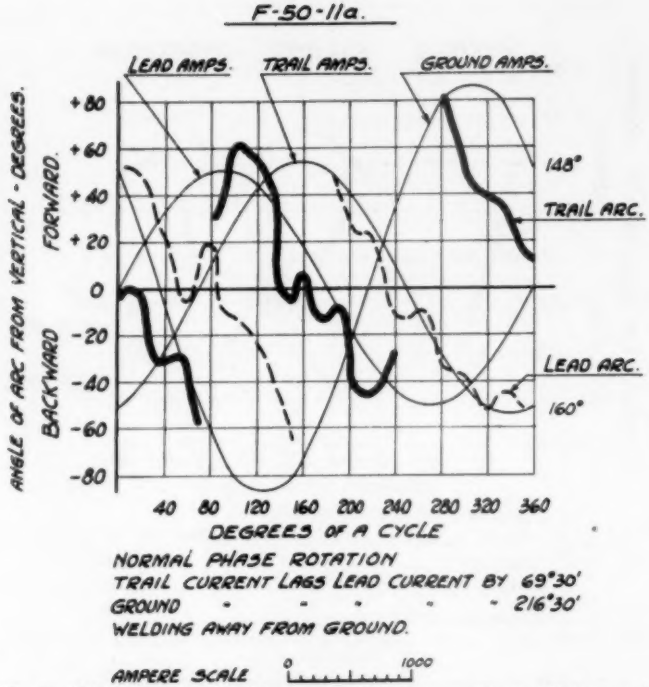

Fig. 10 Deflections of lead and trail arc with delta connection and high ground current

Currents—lead rod, 960 amp.; trail rod, 1040 amp.; ground, 1680 amp.

Two exposures were made on each plate welded—one at the midpoint, and the second near the finish end of the weld. Examination of the films, one frame at a time, provided data on the deflection angle (from the vertical) of the arc *vs.* time. Plots of these angles disclosed the time factors discussed above, the direction of sweep of the arcs, and an indication of arc stability. The curves in Figs. 8, 9 and 10, do not cover the full cycle of 360 electrical degrees, there being gaps where the arc was extinguished (near the zero current axis) or where the photographic image was too dim and indistinct to measure. While these charts indicate the variation in the arc deflections due to changes in the ground current only, they show in a typical way the manner by which arc deflections were plotted under the various welding conditions possible with these circuits.

Welds were then made under a blanket of welding composition using the same variety of conditions in order to correlate weld quality with the arc action observed in the photographs. Examination of the data showed that the theory given above was correct. Other tests have shown that the second explanation of the relationship of ground current to welding direction was the correct one.

COMMERCIAL APPLICATION

In Table 1, typical conditions are recorded for single pass welds from 1/4 in. to 1 in. in thickness and for double-vee welds up to 2 in. in thickness. Welding speeds have often been limited in commercial practice, as well as in the laboratory, by the availability of power and the ability of the drive unit to provide uniform motion. However, the speeds generally obtained in the production of high pressure, large diameter gas and oil transmission pipe, where the tandem welding procedure is most widely used, are as great as 100 in. per min. on 1/4 to 3/8-in. thick material. This compares with 25 to 35 in. per min. obtained where single rod machine welding is practiced.

The tandem procedure can also be used for welding both longitudinal and girth joints of pressure vessels of diameters greater than about 54 inch. It is particularly to be recommended where large numbers of vessels of essentially the same design are fabricated on a production line schedule. In this sort of operation, the large increase in welding speed developed by the a.c.-a.c. tandem procedure results in greatly increased output.

This procedure can also be applied to multipass welds. The advantage here is that the rate of metal deposit is greatly increased, even though conditions are es-

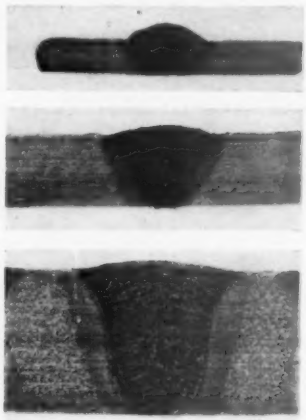

Fig. 11 Typical cross sections of single-pass welds in 1/4- 1/2- and 1-in. plates

Table 1—Typical Conditions for Tandem Unionmelt Welds Using Three Phase Power

Plate thickness, in.	Edge preparation: First side Angle	First side Depth, in.	Root face, in.	Second side Angle	Second side Depth, in.	Leading electrode Diam., in.	Leading electrode Amp.	Leading electrode V.	Trailing electrode Diam., in.	Trailing electrode Amp.	Trailing electrode V.	Ground current	Weldg. speed, ipm	Total rod deposited, lb./ft. of weld	Welding composition fused, lb./ft. of weld
1/4	Square edge					5/32	940	27	5/32	1080	35	1160	83	0.159	0.135
1/2	60°	5/16	3/16			5/32	1040	28	5/32	860	31	1180	43	0.312	0.177
1	35°	7/8	1/8			1/4	1600	37	1/4	1680	47	1740	30.5	0.687	0.620
1	80°	5/16	3/8			1/4	920	32	1/4	860	37	980	30.7	0.707	0.633
				80°	5/16	1/4	1000	32	1/4	1160	36	1140	30.4		
1 9/16	70°	7/16	5/8			1/4	1020	30	1/4	1420	40	1420	22.4	1.578	0.967
				70°	1/2	1/4	1360	32	1/4	1480	40	1400	23		
2	60°	11/16	5/8			5/16	1440	33	5/16	1480	40	1540	17.5	2.286	1.752
				70°	11/16	5/16	1740	35	5/16	1760	41	1920	17.5		

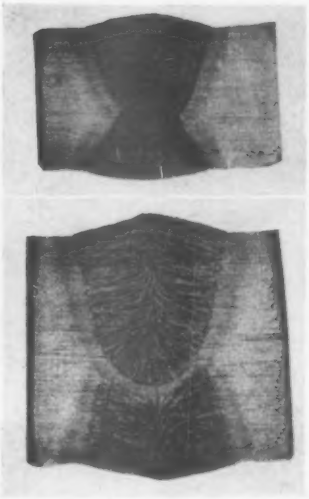

Fig. 12 Typical cross sections of double-vee welds in 1, 1 9/16- and 2-in. plates

tablished so that the thickness of individual layers does not exceed a nominal 1/4 to 3/4 inch. Speeds of 30 to 50 in. per min. per pass have been established, without encountering difficulties from cracking or poor bead shapes. This compares to 10 to 18 in. per min. used for single rod welding.

The two rods used in this method are necessarily closely spaced so that their tips are in a common pool of fused material. The weld nugget differs very little from those of single rod welds as shown by the cross-sections of Figs. 11 and 12. These show well-shaped welds of deep penetrtrtion. However, the control is so vertile that wide, shallow welds can be obtained with equal facility.

The distribution of heat differs from that obtained in single rod welding, as would be expected. In a number of cases, steels or types of joints ordinarily difficult to weld, have been welded by this procedure without experiencing the cracking or porosity that even the best techniques applicable to single rod machine welding could not eliminate.

In summary then, a novel procedure has been developed and applied to commercial fabrication which:

1. Directly utilizes three-phase power for welding purposes, in a circuit which can be designed to provide a high power factor and balanced phase loads.
2. Provides great flexibility in the control of weld quality.
3. Because of this flexibility makes possible unusually high-welding speeds compared to those normally obtained with submerged arc.
4. Results in considerable improvement in energy utilization.
5. Provides a maximum control over the magnetic effects (arc blow) which can be very troublesome under certain conditions of operation.

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(Continued on page 494)

Oxyacetylene Welding and Cutting as Applied to Railroads

Repair and fabrication of parts for passenger and freight cars and of steam and Diesel Locomotives

by W. D. Waldron

A FULL range of oxyacetylene processes are utilized on the Seaboard Railroad. These vary from simple heating operations to automatic shape-cutting, and on up the scale to fabrication and reclamation of alloy Diesel components that must operate in hard service. Welding conditions and routines must be carefully followed in all of this work.

The gradual passing of steam motive power on our railroad has brought about changes in the use of oxyacetylene processes. There is a great difference between the repairs made to a cracked steam locomotive frame on the one hand and on the other hand the air-acetylene heating used to solder the copper in a Diesel traction motor commutator. As you can well imagine, the former operation required one type of skill and the latter demands a very different type. However, as you will find out in the next few minutes, there are still many applications in Diesel maintenance that require the use of the blowpipe with a wide variety of tip sizes.

In the broadest sense, the oxyacetylene flame is used by the Seaboard in practically all metal working. In the mechanical department it is used in the fabrication and repair of parts for passenger and freight cars and of steam and Diesel locomotives.

On track work, oxyacetylene processes are also widely used: worn frogs and switch points are rebuilt; rail ends are oxyacetylene flame-hardened as are also frogs and crossings. Although the Seaboard has not installed oxyacetylene pressure-welded rail, the rails in the Jacksonville station are so welded.

In order to keep within the time limits the discussion of the oxyacetylene processes used on the railroad will be confined to the application at the Jacksonville Shops.

These shops are completely piped with acetylene and oxygen and there are approximately 275 station outlets for these gases. Acetylene is generated by two LP generators with a rated capacity of 1000 cu. ft. per hour. Oxygen in the pipe lines at 60 lb. pressure originates from a liquid storage unit with a capacity of 90,000 cu. ft. All of the thousands of feet of piping carrying oxygen, acetylene and compressed air to all points within the shop is oxyacetylene welded. This pipe varies in size from $^1/_2$ to $4^1/_2$ in. made with wrinkle bends.

Figure 1

In the shop where cars undergo heavy repairs many station outlets are erected above floor level like the one shown in Fig. 1. This is a good arrangement to use between the car lines when no columns are available. In this shop there are 145 stations and in a heavy period of work 90 blowpipes will be used. Some of these will be cutting blowpipes with which rivets are removed with the piercing nozzle, or defective metal cut out. Many welding blowpipes are used in this building as a quick source of heat for bending and

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Figure 2

straightening. Oxyacetylene welding is also of importance in some repairs that are made.

Close to this car repair shop is a building housing an automatic shape-cutting machine which is used for preparing plate shapes for car repair work. It is also used for cutting slack washers, and follower blocks.

The railroad has many gondolas for handling phosphate rock. The drop doors of these cars corrode badly and the replacements are taken care of by fabricated doors that are built in our shops. Figure 2 shows the die-stamped plate being welded on one of four corners that are similarly treated. Prior to forming, each corner is manually flame-cut so that when welded the corners are neat and smooth. This is an example of where the heating of the welding blowpipe is used to heat a small section that the welder can hammer to a smooth curve prior to welding with steel rod using a No. 20 tip. Figure 3 shows that no after finishing is necessary on the resulting smooth weld.

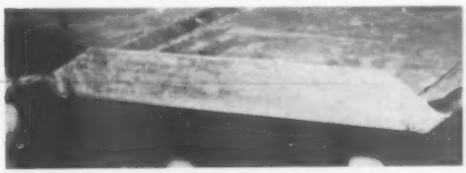

Figure 3

Figure 4

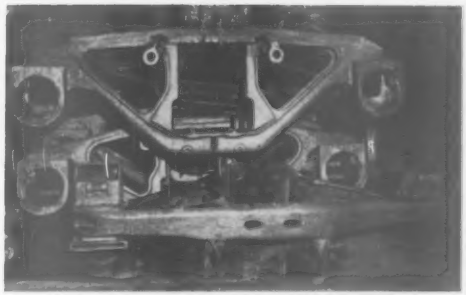

Figure 5

Oxyacetylene welding is employed to repair cast steel freight car truck sides and some parts of couplers. Flame-gouging is used to remove steel in the damaged area before welding as illustrated in Fig. 4. Prior to welding a truck sideflame it is preheated to 600° F. You see here a gouge being quickly made in a crack that extends through about three quarters of the cross section. With the gouging nozzle the operator gets down to the bottom of the crack. A No. 19 nozzle was used with oxygen line pressure of 60 lb. and low pressure pipe line acetylene.

The flame-gouged area now oxyacetylene welded using high-strength alloy rod is barely visible in Fig. 5. Using oxyacetylene welding the worn bolster wearing surfaces are built up using a steel rod. There was also a repair made on a break in the hub side of the journal box. Brake hanger pin holes that wear over size are frequently built up, although in this frame this was not required. All of the acetylene repairs made to this frame required no after-machine. Following all repairs the frames are heated to 1550° F. and cooled in shop air.

This shop also builds up the coupler parts shown in Fig. 6. At left is type "E" knuckle lock, center a type "D" lift and at right an 11-in. knuckle. Before oxyacetylene welding, using high-strength steel rod, the parts are heated to 1200° F. This speeds the welding and eliminates the need for postnormalizing. The

Figure 6

Figure 7

smooth deposit laid down by skilled operators eliminates need for after grinding.

While making the pictures for this paper we came across this hand flame-cutting operation illustrated in Fig. 7, which in one way or another is routine in a large railroad shop. Because of the type of construction, the worn slewing gear of a locomotive ditcher could not be pressed off. Using a No. 8 nozzle, 60 lb. oxygen pressure and low pressure acetylene, the gear with a 7-in. hub was easily removed without damaging the axle.

Brake heads, which hold brake shoes, are subject to heavy wear and are reclaimed in large volume. From left to right in Fig. 8 is shown brake head built up the same type prior to building up, a freight car brake head built up, the same type reclaimed. This leaves the brake head at the right and the small key in the foreground. The Diesel brake heads are steel and are built up with high strength steel rod. Freight brake heads shown here are malleable and they are built-up with cast-iron rod to increase their wearing quality. The worn key which fits the head at the right is built up, as is also the "conventional" brake head at the right into which this fits. Following the building up of worn

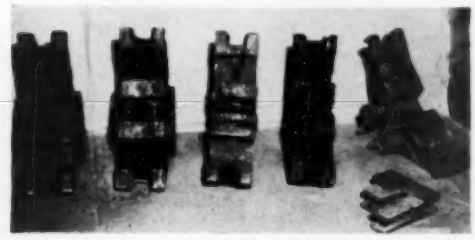

Figure 8

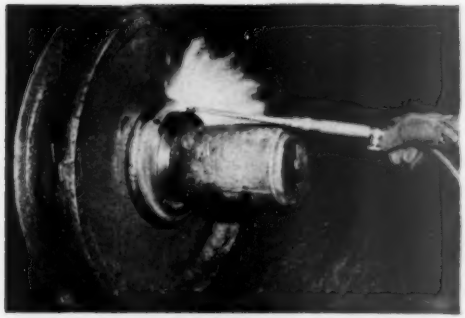

Figure 9

Figure 10

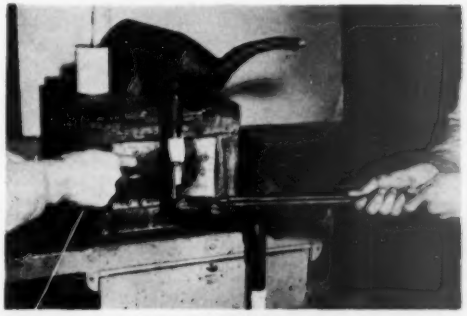

Figure 11

Figure 11a

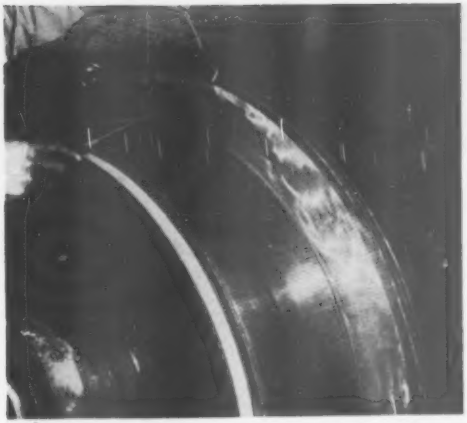

Figure 12

surfaces, using a No. 60 tip, the heads are normalized at 1000° F. No machining of deposited metal is needed.

The balance of this paper will be devoted to the fabrication or reclamation of Diesel locomotive parts by oxyacetylene or air-acetylene.

Let us first consider heating applications. The quick, clean, intense heat of the oxyacetylene blowpipe is being used in Fig. 9 to heat and expand this Diesel wheel dust guard so that it can be removed. The No. 150 tip operating off piped supplies of gases produces enough heat so that a guard is removed in one minute. The same flame is used to expand dust guards so that they can be fitted on the axles. Six or eight guards are stacked up and the flame is played down two sides of the pile, and then they are quickly placed on to the axles one at a time.

Figure 13

An expanding application is the flame-cutting of parts for Diesel brake rigging. In Fig. 10 a Diesel brake lever is being flame cut at 16 in. per minute from forged axle steel $1^1/_4$ in. thick using a No. 6 cutting nozzle. Producing parts such as this means major savings in Diesel replacement expenses.

Application of the air-acetylene flame to reclaim and assemble Diesel components is important to the Seaboard.

Shown in Fig. 11 is a traction motor coil lead to which will be soldered a lug using 50–50 solder, air-acetylene torch with a No. 4 tip. Traction motor leads shown in Fig. 11 (*A*) are similarly soldered and the volume of this work is large.

The air-acetylene flame is used to solder main generator commutator risers as illustrated in Fig. 12. Solder is 95% tin and 5% antimony for this application. The air-acetylene flame is also used to remove coil ends from risers preparatory to rewinding armatures.

In work on Diesel oil and water coolers a lightweight oxyacetylene blowpipe with a No. 4 tip gives the required heat. This is an all-copper oil cooler element which frequently develops leaks, requiring the removal of old solder and resoldering. In Fig. 13 the operator is shown laying a soft solder during the rebuilding of the cooler.

Diesel truck equalizers of forged steel are subject to heavy wear on the foot and corners. Using a No. 80 tip these worn areas are built up to surface with a deposit of steel rod varying from $^1/_{16}$ to $^1/_2$ in. thick. The torch and a flatter are all that are needed to produce a smooth ready-to-use finish as shown in Fig. 14.

Going back to the electrical department again, Fig. 15 shows an interesting application on Diesel brush holders. The tension spring support shaft holes on these bronze parts wear out of round and to eliminate this condition we solidly weld up the holes and redrill.

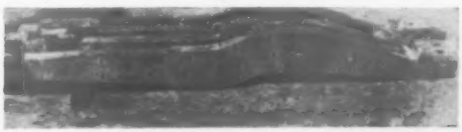

Figure 14

Figure 15

Figure 16

The part at the left is in the as-welded condition and that at the right is redrilled ready for use. These parts are often pitted and any such condition is taken care of by filling in with 95–5 solder using the oxyacetylene flame.

Here are some other interesting bronze-welding applications. Figure 16 shows a Diesel locomotive thrust end bearing that is reclaimed by oxyacetylene welding. The badly worn original cast bronze was melted out with the oxyacetylene flame and a new $^1/_2$ in. deep deposit was made with the torch and then the part was machined, making it equal to new.

In Fig. 17 are cast-steel Diesel locomotive brake friction arms that are rebuilt with appropriate bronze rod. The center part and the one at the left are opposite sides of the friction arms used in freight locomotives, the part at right being for passenger locomotives. In the case of the latter a $^1/_8$-in. layer of bronze is deposited and the part is machined to size. The freight locomotive parts, built up in two areas with about $^1/_{16}$ in. of suitable bronze, require no after finishing.

Traction motor suspension bearings, one of which you see in Fig. 18, wear down on the hub face and are reclaimed by building them up about $^1/_4$ in. with bronze and then machining to dimension. This particular type is for a freight locomotive. Those used on passenger locomotives are lined with a bearing metal. This metal is prevented from melting out during the welding on of the bronze by immersing the part in water up to a level that permits welding.

The value of the oxyacetylene process in Diesel reclamation is illustrated by these two cast-iron compressor clutch sheaves shown in Fig. 19. The teeth in this part and also the center cupped hole became badly worn. They are machined out and the base metal is undercut about $^1/_4$ in. Next, they are preheated to 800° F. and the bronze welded deposit is made with the part in the furnace. Using a No. 60 tip, required type of bronze and flux, the built-up deposit is made with the part lying flat. The 1- by $1^1/_2$-in. deposit is made in $^1/_4$-in. thick layers that are made progressively around the wheel like a cork screw. This

Figure 17

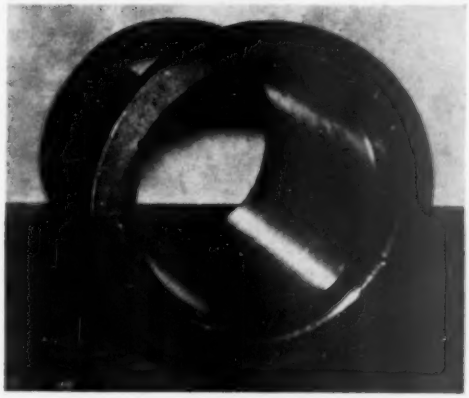

Figure 18

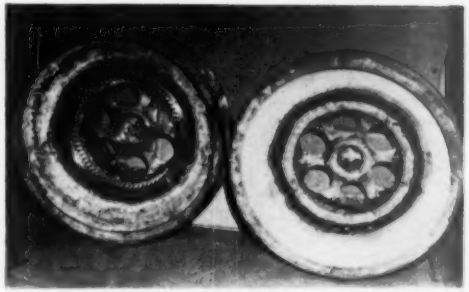

Figure 19

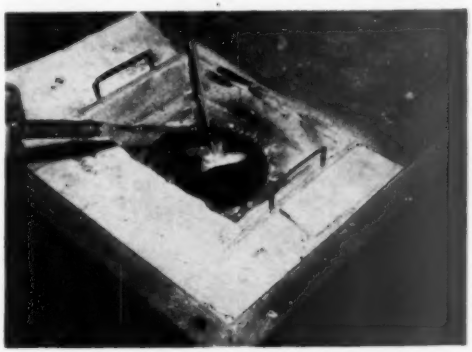

Figure 20

method prevents the parts from warping. A No. 60 tip is used with oxygen and acetylene from the pipe lines. This part is 24 in. in diameter and the rim section is about $^3/_4$ in. thick. Following welding the part cools in the furnace for three days. The wheel at the right is in the as-welded condition, and that at the left has the gear and center parts machined.

One of the most important Diesel locomotive parts reclaimed from the standpoint of savings in the cylinder head. Cylinder heads, regardless of type of locomotive, are costly and the severe service they are subject to brings about considerable maintenance. Figure 20 shows how the valve seats and injector hole are built up on the Seaboard. Heads are first cleaned and then all worn and cracked areas are machined in preparation for welding. The head is placed in one of a battery of charcoal fired ovens and preheated to 1400°F. Carbon plugs in the valve seat openings and a steel disk in the injector hole hold the molten welding metal in the desired locations. Welding is done as shown here, using a No. 60 tip, $^1/_8$-in. cast iron rod, oxygen at 40 lb., and low-pressure acetylene. Cracks at stud holes are also welded. Following welding the furnace is closed up and the part is left to cool slowly over a three-day period. Hardness of deposited metal is about the same as the base metal and a minimum of trouble has resulted from porosity or inclusions. At the left

Figure 21

in Fig. 21 is a head as welded and at the right is the same type following one of the first machining operations.

In conclusion, I would like to say that the Seaboard Air Line Railroad finds a wide scope for the oxy-acetylene flame. In a paper of this length it is impossible either to describe in detail how the flame is used in specific applications or all of the applications in the various shops and departments of the railroad. However, I feel sure that the uses of the flame I have covered in this paper are standard and they reflect the other applications I have been unable to cover.

Resistance- and Arc-Welding Conference

Quality control, instrumentation, power supply, resistance welding, fundamental arc and arc welding were the general subjects discussed at Detroit on April 16th, 17th and 18th

by B. E. Rossi

THE Third Annual Welding Conference held in Detroit on April 16th, 17th and 18th under the joint sponsorship of the AMERICAN WELDING SOCIETY, The American Institute of Electrical Engineers and the Industrial Electrical Engineers Society of Detroit was highlighted by many informative and timely technical papers on resistance and arc welding. Among the many topics covered were quality control, military specifications, instrumentation, power supply for resistance-welding machines, resistance-welding problems, arc phenomena and arc-welding studies.

B. E. Rossi is devoting part time to the duties of Assistant Editor to the WELDING JOURNAL.

QUALITY CONTROL

The morning session on Wednesday, April 16th, was devoted to the problem of quality control as applied to resistance welding.

"Elements of Quality Control in Spot Welding Aluminum for Aircraft" was the subject of the first paper presented at the conference. Its author, F. H. Matthews, Boeing Airplane Co., Seattle, Wash., pointed out that in the spot welding of aluminum for aircraft, the degree of quality control is reflected directly in the product. Each stage of the process is easily adapted to certain types of control that simplify the prediction and analysis of difficulties. Also, quality control standards assure consistency of practices throughout various facilities.

J. Maltz and N. E. Promisel of the Bureau of Aeronautics, Navy Dept., presented a talk on "Military

Aeronautical Spot and Seam Welding Specifications." The authors traced the development of military specifications governing the application of the spot- and seam-welding processes to military aircraft. They emphasized that it had been, and it is, the aim of the writers of these specifications to encourage the orderly growth of military spot welding from a limited usage in noncritical and nonstructural applications toward full structural application. At first, such growth had to be governed by controls and procedures which would assure the maximum consistency and optimum strength. Later, when a firm foundation had been provided, these controls had been eased in the interest of high production and simplified sampling. The authors also brought out in their discussion that, largely because of the need for additional design data, the use of seam welding for other than noncritical and nonstructural applications is still very limited.

"Industry's Answer to ANW Specifications" was the viewpoint expounded in the papers by F. L. Brandt, Thomson Electric Welder Co., Lynn, Mass. Mr. Brandt gave a detailed account of the latest developments in resistance-welding machines intended to produce the highest quality welds. He remarked that, as part of these improvements, the machines are now getting larger and heavier in order to produce the greater welding forces required with satisfactory rigidity.

INSTRUMENTATION

Instrumentation for resistance welding was the theme of the papers presented at the Wednesday afternoon session.

Reidar P. C. Rasmusen and Robert C. McMaster of Battelle Memorial Institute, Columbus, Ohio, spoke on the subject of "Resistance-Welding Instrumentation —Past, Present, and Future as Applied to Quality Control." They reviewed briefly the progress of resistance welding from the time of its invention and indicated the increasing role played by instrumentation in that progress. The authors also stressed the point that instrumentation should be a tool or a guide, rather than an absolute factor to be relied upon, in controlling the long list of empirical variables associated with resistance-welding quality control. In addition, they listed the variations in instrumentation that are useful under different conditions, with some of the limitations of each.

"Instruments to Improve the Operation of Single-Phase and Three-Phase Resistance-Welding Machines" was the title of the paper presented by William R. Stern, The Brush Development Co., Cleveland, Ohio. The measurement of such welding variables as electrode force and welding current by means of amplifiers and direct writing magnetic oscillographs was dealt with in detail. Among other things, the author denoted that the use of modified direct-writing oscillograph and amplifier allows the study of the sequential firing of ignitron tubes employed in a three-phase welding machine. These oscillographs show 180 cycles per second trace of the firing of each ignitron bank and, thus, make possible the analysis of the operation of the welding machine. The use of instruments in the proper adjustment of the welding machine, the recording of the operation of a solenoid operated air valve and the measurement of "squeeze," "hold" and "off" times were also covered by Mr. Stern.

V. H. Kraybill and R. E. Young, Public Service Company of Northern Illinois, and M. Fisher, Jr., of the University of Illinois, gave the next paper. Entitled "New Devices for Measurement of Welder Voltage Drops on a Power System," this paper provided a description of unique methods for measuring small voltage variations of the order of 2% and less; also, it discussed the development of a new instrument for analysis of the voltage fluctuations caused by the low-frequency type welders.

"Spot-Weld Monitoring by Resistance Change" was the problem undertaken by Herbert D. Van Sciver, The Budd Co., Philadelphia, Pa. The author reported that, while searching for a means of nondestructively determining the quality of a spot weld, it had been discovered that if the highest resistance across the electrodes be taken as a reference, then the percentage drop in resistance may be taken as a function of weld development. He also brought out that a statistical study involving ranges of current, time, electrode force, metal thickness and electrode wear had confirmed the theory that the changing resistance is a predictable function of weld size.

The study covered in the next paper, "Electronic Control for Monitoring the Resistance Change During a Spot Weld," was directly associated to the investigation described by Mr. Van Sciver. The authors, S. S. Barnhart and W. B. Hills, General Electric Co., Schenectady, N. Y., outlined the development of this control and explained that the instrument measures the instantaneous resistance between the spot-welding electrodes by dividing voltage across the electrode tips by the welding current flowing through them. After the inital resistance variations subside, a reference resistance is set up. When the resistance falls a preset percentage of this reference value, the welding current is stopped. Suitable lights indicate if the preset resistance change occurs before the minimum weld-time setting, between minimum and maximum or after the maximum weld-time setting; that is, the monitor shows whether the change occurs within the acceptable range of time.

POWER SUPPLY FOR RESISTANCE-WELDING MACHINES

A symposium on power supply for resistance-welding machines was held on Thursday morning, April 17th. The discussion was opened by E. L. Bailey, Chrysler Motor Co., Detroit, Mich., who stated that the scope of this session was to direct attention to the special

electrical features involved in satisfactory resistance welder installations, so that the full analysis developed for a welding project could be readily understood and utilized.

Following Mr. Bailey's introductory remarks, W. G. Bostwick, Precision Welder and Machinery Co., Cincinnati, Ohio, presented a paper on "Resistance Welding Machines—Their Rating and Characteristics of Their Load." This paper treated such electrical aspects of resistance welders as impedance, secondary volts and short circuit and welding current, as well as kva. demand, duration, power factor and duty cycle of resistance welder load.

"The Power Company's Supply System" was the topic discussed by H. W. Tietze, Public Service Electric and Gas Company of New Jersey. Mr. Tietze outlined the methods of analysis and design which must be considered by the utility in providing adequate service to the resistance-welding machine without interference to others. The service to a welding machine, he stated, is a problem of economics, involving not only the considerations on the customer's side of the meter, but also the utility investment and adequate compensation for the services rendered.

W. K. Boice, General Electric Co., New Haven, Conn., brought to the fore the problems of the industrial user of power who must provide power distribution equipment within his plant to supply resistance welders. The title of his paper was "Information for Power Users," and the subject matter covered methods for estimating the input to welders, procedures for calculating voltage drop, problem of light flicker, problem of providing adequate voltage for good welds and methods for calculating required current carrying capacities. Mr. Boice also gave an explanation of the several types of capacitor applications and made certain suggestions for selecting the type of distribution system, feeder circuits and protective equipment.

"Typical Installations" of resistance welders were described and evaluated by C. E. Pflug, Nash Kelvinator Co., Kenosha, Wis.

RESISTANCE WELDING

The resistance-welding process was the theme of the speakers at the Thursday afternoon session.

I. W. Johnson, General Electric Co., Schenectady, N. Y., spoke on "Up and Down Slope in Spot Welding." He reported that, on the basis of actual qualifying tests performed on several alloys such as 24ST aluminum alloy, 347 stainless steel and two chrome steels, "up and down slope control" makes it possible to obtain the best spot welds with the simple, low-cost, single-phase equipment. This control regulates not only the start of the current, but also the decay of the current at the finish of the weld.

"Comparison of Frequency Changer Circuits" was the subject of the paper by H. V. Nelson, General Electric Co. Schenectady, N. Y.

"A New Method of Controlling Platen-Displacement vs. Time During Flash Welding" was described by E. E. Moyer and W. F. Savage, Rensselaer Polytechnic Institute, Troy, N. Y. They indicated that a study of the flash welding characteristics of various materials carried forward at R.P.I., had resulted in the development of a new and improved method of controlling platen-displacement vs. time. Specifically, the authors said, an all-electronic system of controlling the platen velocity was designed, constructed and applied to an existing welder. Using this system, they were able to duplicate flashing patterns with an error of less than 2% of the calibrated values on the control dials. In the course of a year's operation, during which the equipment was operated on the average of about four hours per day, no maintenance had been necessary and the original calibrations still held.

J. R. Fullerton, Ryan Aeronautical Co., San Diego, the last speaker of the day, concerned himself with "Problems and Equipment in Aircraft Spot Welding." He commented that, in today's modern aircraft or component plant, it is quite common to see resistance-welding equipment which varies in size from small simple tack-welding equipment to large complex, three-phase machines capable of making crack-free structural welds in aluminum alloys of 0.125 in. in thickness or heavier. Mr. Fullerton also made the point that, since the materials joined by spot and seam welding vary widely in composition and characteristics, it is necessary that modern resistance-welding equipment be quite versatile and incorporate some or all of the accessory equipment available. Each alloy presents its own particular welding problems which may justify or demand special equipment or accessories.

FUNDAMENTAL ARC

Four papers on fundamental arc-welding investigations were delivered at the morning session held on Friday, April 18th.

T. B. Jones and Merrill Skolink, Johns Hopkins University, Baltimore, Md., were the authors of the first paper. Their topic was "Characteristics of the Tungsten Arc in Argon-Helium Mixtures." They related that the d.-c. tungsten arc in argon-helium mixtures at atmospheric pressures had been investigated under controlled laboratory conditions. The electrodes used in this investigation were $^1/_8$-in. diameter tungsten rods and the current range covered was 10–100 amp. Mixtures over the complete range from 100% argon to 100% helium were studied and it was found that, for all mixtures, the presence of each gas was manifested by its effect on the electrical performance and appearance of the arc. However, the influence of the argon was dominant and, for mixtures containing 15% or more of argon, the characteristics of the arc were more nearly those of the pure argon arc. The decrease in arc voltage from 0 to 15% argon was as great as the decrease in voltage from 15 to 100% argon.

"The Hissing Arc and Radio Frequency Oscillations" was the problem discussed by Bernard List, Battelle Memorial Institute, Columbus, Ohio, in cooperation with T. B. Jones, Johns Hopkin's University, Baltimore, Md.

R. J. Krieger, Ohio State University, Columbus, Ohio, talked on "High-Speed Photography—A Technique for Arc Research." Discussing the technique used in a study made at the University, Mr. Krieger reported that a specially designed, electronically controlled, welding head had been placed in a partially shielded framework to facilitate the taking of high-speed motion pictures of the arc, from close range, through a small opening in the shield. Preliminary work has indicated, he added, that high-speed photography should be a very useful tool in welding arc research.

A paper on "Some New Instruments to Aid in the Study of the Welding Arc" was presented by L. P. Winsor, Rensselaer Polytechnic Institute. The author gave a description of two new instruments designed to aid the study of arc stability. For the d.-c. arc, a "rms. voltage deviation meter" had been modified to include a high-pass filter in the input circuit, thus providing a tool for the study of the frequency distribution of the fluctuating component of the arc voltage. For the a.-c. welding arc, an electronic instrument had been built to measure the proportion of reignition peaks exceeding any assigned value; thereby supplying a means for making a statistical study of the reignition voltage. Mr. Winsor advised, further, that both instruments have now been developed to the breadboard stage and that measurements have been made for several types of welding electrodes as a function of both arc current and arc length.

ARC WELDING

The general subject considered at the last technical session of the Conference, Friday afternoon, dealt with arc welding.

The opening paper was entitled "Oscillographic Studies of the Shielded Inert-Gas-Metal-Arc Welding Process." Its author, R. W. Tuthill, General Electric Co., Fitchburg, Mass., discussed the arc-voltage, arc-current and machine-voltage characteristics during welding with the inert-arc process on different metals with different shielding gases. He pointed out that these characteristics show that a critical voltage range exists for each wire, for each current that may be used on the wire. Above this critical voltage, arcing and welding characteristics are radically different from the characteristics prevailing below the critical voltage. Mr. Tuthill concluded his presentation by making a number of recommendations on those conditions of welding which will produce optimum results.

C. R. Dixon and P. B. Dickerson, Aluminum Company of America, New Kensington, Pa., spoke on "Arc-Welding Process for Making Electrical Connections Between Small Aluminum Wires." They stated that there is now available special arc-welding equipment which can be used to fuse the ends of twisted pigtails joining aluminum conductors. No surface preparation is necessary to make these wire joints, other than to remove the insulation so that a good ground connection can be made. The weld is effected by striking an arc between the wire and a carbon electrode. No flux or protective atmosphere is used.

"Power Supply for Three Phase Tandem Arc Welding" was the paper presented by Norman Schreiner, Linde Air Products Co. N. Y.

The final paper of the session was presented by E. Steinert, Westinghouse Electric Co., Pittsburgh, Pa. His subject was "Rectifier Welders."

As a whole, the papers presented at the Third Annual Welding Conference have contributed much needed information to our present knowledge of the resistance- and arc-welding processes. The authors and co-authors, as well as the sponsors of the conference, are to be commended for a job well done.

(*Continued from page 485*)

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(*Continued on page 499*)

New Million Dollar Liquid Oxygen/Nitrogen Plant

Houston Oxygen Co. builds modern producer of pure oxygen, nitrogen, argon

by J. F. Brinley

ANTICIPATING the rapidly expanding needs of the Southwest's roaring industrial development, the Houston Oxygen Co. recently put in operation its new million-dollar plant for the production of pure liquid oxygen and liquid nitrogen, and pure oxygen, nitrogen and argon gases.

Simultaneously, meters started ticking on the world's first pipe line to supply multiple industrial customers with pure, dry oxygen gas.

Surprisingly few individuals realize the many and complicated processes required to convert tremendous quantities of ordinary air into a comparatively few drops of liquid oxygen and liquid nitrogen. Yet from these liquids are derived the large quantities of pure gases—oxygen, nitrogen, argon, etc.—so necessary to an amazing array of industries, so vital to the national defense effort.

For these liquids and gases play an important role in many phases of petroleum drilling, production, refining and transportation; steel and other metals manufacture and fabrication; chemicals production; medicine and surgery; science and research; shipbuilding and shipping; fire-fighting; aviation; war equipment; and the manufacture of countless products essential to our national economy.

This plant's engineers tell you "The whole thing is really very simple—primarily involving the processes of compression, expansion, condensation, distillation and evaporation."

But anyone fortunate enough to tour the plant soon learns that is a masterful understatement of fact. For there is ample evidence of many another complicated process employed here—not to mention the engineering secrets quite obviously concealed within the steel columns and other apparatus used.

It is undoubtedly true that the oxygen industry utilizes the world's *only* free raw product—air. It is equally true that the end products made from this atmospheric air are quite astounding.

For example, consider liquid oxygen, which relatively few persons have ever seen. It bubbles and looks like boiling water, is odorless, crystal-clear and slightly bluish in color. It pours like water, but is strongly magnetic and in this respect somewhat resembles the action of mercury. The temperature of liquid oxygen, as drawn from final processing, is −183° C. (that is a mere 329° F. below the freezing point of water!) and it rapidly and constantly evaporates, giving off a steamlike vapor. Liquid oxygen cannot be stored or carried in a sealed vessel because the creation of vapor is continuous and it would, if confined, quickly build up a pressure and cause a violent and dangerous explosion. It is stored in heavily insulated tanks to resist temperature loss and consequent evaporation.

Liquid nitrogen is as colorless as water, but otherwise looks and acts very much like liquid oxygen. Its temperature, as drawn from final processing is −196° C. and it must be handled similarly to liquid oxygen.

AIR—THE SOLE RAW PRODUCT

But some of the processing can be told, and perhaps somewhat clarified by reference to the Simplified Flow Chart; which, incidentally, eliminates at least 75% of this "simple" operation!

First, air is filtered and taken from the atmosphere by the first stage of the 5-stage compressor battery, and here it is compressed to 30 psi. Thence the air is sent through dual Scrubber Towers (located outside of the building and operated with dual lyepumps); from which it is delivered to the second compressor stage, where it is further compressed to 115 psi.

Next, this air goes to the third compressor stage, where it is compressed to 400 psi.; followed by the fourth stage compression to 840 psi. And finally the fifth stage turns the air out at 2350 psi. After the air leaves each compressor stage, it is cooled as it passes through a heat-exchanger before going to the next stage . . . this whole compression process being done in series, step-after-step.

MOISTURE REMOVED AND AIR COOLED

Now this air under 2350 psi. goes to a cold dryer,

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where the moisture in the air is frozen off under a temperature of −35° C. The cold dryer also serves other purposes in the latter stages of processing, as will be seen later. The cooled air leaves this cold dryer divided into two separate parts, which could be identified as Part A (comprising about one-third of the volume) and Part B (comprising the balance).

Part A of the air is then passed through a heat-exchanger and cooled to −150° C.; thence it passes to a liquefying exchanger where it is cooled to −175° C. Next, this part of the air (still under 2350 psi. pressure) passes through an expansion valve, where it is expanded to 75 psi. just before the line enters the rectification column. And it is this terrific expansion which converts a high percentage of the Part A air to a liquid. Both the liquid air and the remainder of gaseous air then flow into the rectification column.

EXPANSION ENGINE A KEY FACTOR

Back-tracking for a moment to the cold dryer, *the other Part B* air, comprising about two-thirds of the original air volume, also leaves the cold dryer at −35° C. Still under 2350 psi, it goes to a high-pressure expansion engine. Here the pressure is expanded to 75 psi. which lowers its temperature to −165° C. This air now passes through dual filters to remove any trace of oil picked up from the expansion engine, since oil traces would be highly dangerous in later processing.

This Part B air is then delivered to the same liquefying exchanger through which the Part A air travels; but Part B air is kept entirely separate from the Part A air, so they in no way co-mingle within the liquefying exchanger. The Part B air from the expansion engine is cooled further to −175° C. in the liquefying exchanger and then it also, but separately, enters the rectification column. So now we have all of the compressed air, Parts A and B—some as liquid air and some as gaseous air—in the rectification column.

We learn from the engineers that the expansion engine used in the Houston Oxygen Co. process, is especially important . . .that it is one of the key points for making liquid oxygen in volume production with the high efficiency here attained. As a by-product of this expansion engine—which is powered by the force of the high-pressure air as it expands in the engine—its flywheel utilizes a belt to drive an electric generator, which in turn supplies part of the plant's power and lighting requirements.

RECTIFICATION COLUMN

The rectification column functions primarily as a double column, the lower portion being termed the first rectification column, and the upper portion being called the second rectification column. The column contains a gel-absorber to trap and *remove any trace of acetylene gas* with which the original air from the atmosphere might be contaminated. Thus the column is made safe against explosion. The rectification column

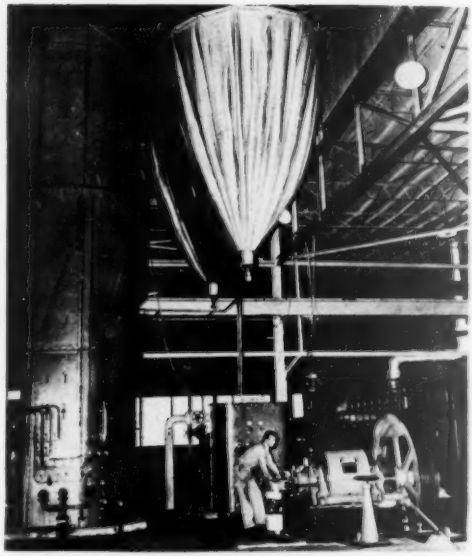

Fig. 1 At left is the base of the rectification column; and at right the expansion engine which plays such an important role in efficient volume production of pure, dry oxygen and nitrogen and argon gases at Houston Oxygen Co.'s new plant. In upper center is the crude argon balloon

also contains three other separate rectification systems and many additional units employed in the various refining processes.

Both parts of the air, as above traced, enter the first (lower) rectification column. Here, rectification starts, and by a series of distillations the liquid air is separated into crude liquid oxygen and crude liquid nitrogen.

Each of these crude liquids is then expanded from 75 to 6 psi. and both enter the second (upper) rectification column, where *pure* rectification takes place. This results in (1) a 99.7% pure liquid oxygen (with a temperature of −183° C.), (2) a highly refined oxygen gas and (3) a "nearly pure" nitrogen gas in the second rectification column.

NITROGEN HIGHLY REFINED

This nitrogen gas is taken off and transferred to another rectification column within the main column structure. Here 99.9% pure nitrogen gas and 99.95% pure liquid nitrogen are produced; with the nitrogen gas being returned to the cold dryer unit before passing on to a nitrogen gas holder; and the pure liquid nitrogen being drawn off (with a temperature of −196° C.) and stored in thermos flasks for delivery to laboratories for testing purposes, research, etc.

ARGON GAS PRODUCTION

A portion of the highly refined oxygen gas is drawn

off the second rectification column and transferred to another rectification column within the main column structure. Here it is liquefied by a condenser and separated into oxygen gas and crude argon gas, the latter being stored in a large argon balloon suspended under the roof of the building. This crude argon gas is then returned to still another rectification system within the main column structure, where it is highly purified (to 99.9% purity) before being returned through the cold dryer unit and passing on to a pure argon gas holder. The crude argon gas residue, is also returned to the cold dryer and then discharged to atmosphere as waste.

Returning again to the second rectification column, the dry oxygen gas left from processing here is drawn off and returned to the cold dryer unit, where it is more highly refined to 99.7% purity before passing on to a pure oxygen gas holder.

LIQUID OXYGEN AND OXYGEN GAS

From the second rectification column, the liquid oxygen is also drawn off and transferred to two liquid oxygen storage tanks. *Each* of these tanks holds the liquid equivalent of 1,000,000 cu. ft. of oxygen gas.

This liquid oxygen in the two storage tanks is the main source from which volume production of oxygen gas is produced. From these tanks the liquid oxygen is pumped under 2200 psi. to two evaporator heaters which convert the liquid oxygen to large volumes of dry oxygen gas. Part of this is conveyed to gas manifolds at the cylinder filling stations, where the familiar steel oxygen cylinders are charged with 99.7% pure oxygen gas under 2200 psi. pressure —ready for delivery to small industrial and medical users of oxygen.

OXYGEN PIPE LINE

Part of the dry oxygen gas produced here feeds the new industrial oxygen pipeline which has just been placed in service.

From Houston Oxygen Co.'s new plant, located on W. 11th St. in the western section of Houston, the 3 in. oxygen pipe line runs southeast and already supplies many large plants. Among others supplied, in the order of their location on the pipe line, are the large plants of Engineers & Fabricators, Inc. (manufacturers of heat exchangers, coolers, reboilers, condensers and other heat transfer and pressure equipment), the Southwest Plate Division of Southwest Steel Products (fabricators of steel storage tanks, pressure vessels, etc.), Nowery J. Smith Co. (galvanizing, electroplating, steel bolts, etc.), Tyson Smith Co. (makers of steel tanks, heaters, separators, treaters, etc.) and Wyatt Metal & Boiler Works (steel plate fabricators and erectors).

The pipe line is laid almost to the intersection of Hempstead and Katy Rds., and rights-of-way have been granted to extend it another four miles due west along

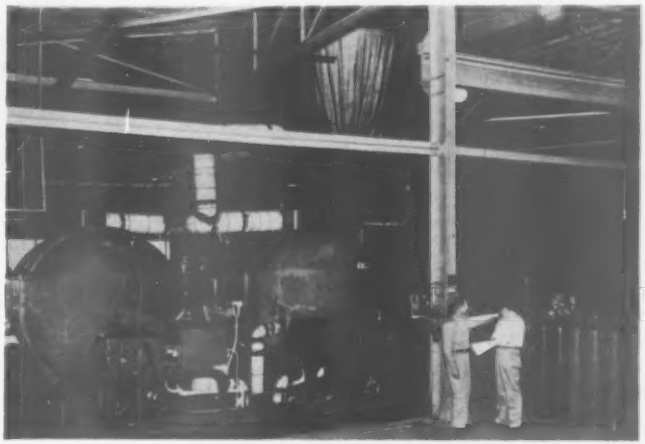

Fig. 2 At left are seen two liquid oxygen storage tanks, and in front of each a liquid oxygen high-pressure pump. At right, one of the cylinder filling stations and oxygen gas manifolds. Harper Avis, in white shirt, is plant superintendent for Houston Oxygen Co.

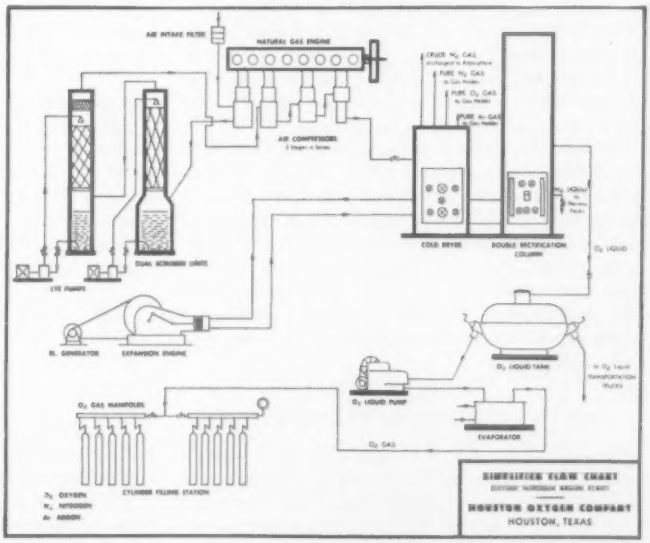

Figure 3

Katy Rd. to supply many other industrial oxygen users in that area.

Houston Oxygen's general manager, Al Herzstein, who is also Secretary and Treasurer of the company, said, "Our new plant is strategically situated to run additional pipe lines in various directions to supply the other fast developing industrial areas in this section of Houston.

"This pipe line was tested under 200 psi. pressure, but it is operated under 100 psi. only. So there is an exceptionally high margin of safety. We deliver dry oxygen gas of 99.5% or better purity to our customers, each of whom has a meter for measuring their consumption. So you see it is really like a fuel-gas line in operation."

Stupendous quantities of pure oxygen gas are used for welding and cutting metals; for steel making and fabricating; by hospitals and doctors for respiration, oxygen tents, etc.; by the air corps for flyers in high altitudes; by ordnance depots in making guided missiles and certain types of bombs; by commercial airliners for pressurizing cabins flying high altitudes; and an amazing number of other applications which the average person seldom thinks about.

BETTER SERVICE FOR LARGE OXYGEN USERS

A. K. (Al) Smith, genial President of Houston Oxygen Co., commented, "the economical advantages of installing central system oxygen and acetylene lines, *within industrial plants* using welding and cutting operations, are yet to be utilized in full measure. When the usual individual cylinders need no longer be handled, regulators and hoses no longer switched from empty to full cylinders, and lost production due to such delays no longer suffered—these savings in labor costs alone will represent a direct and sizable contribution to any customer's profits, without even considering the greatly reduced hazard factors. Our increased and modern facilities now bring such improvements within easy reach of industries in the areas we serve."

The use of such central system oxygen and acetylene lines within industrial plants will be greatly increased by this company's new facilities for providing customers (not served by their pipe lines) with large banks of as many as 50 permanently placed tubes, each 20 ft. long, for the storage of oxygen. Heretofore, smaller storage banks were mounted on large, flat trailer-trucks; and when these emptied, they had to be towed back to the oxygen plant for refilling, meantime being replaced by similar equipment.

LIQUID OXYGEN TRANSPORTATION

Cyrus K. Rickel, Vice-President of the company, explained, "We are now completing the building of a fleet of specially constructed tank trucks to carry liquid oxygen under atmospheric pressure right out to the customer's permanently placed storage bank.

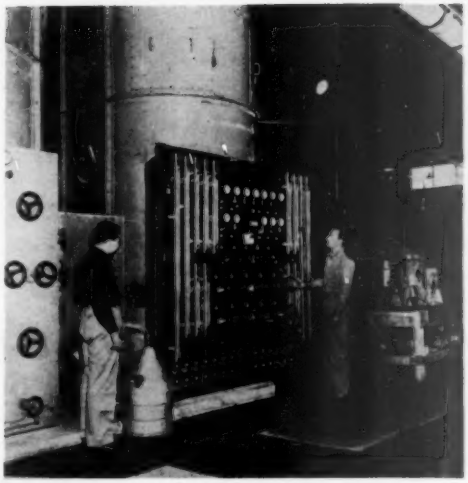

Fig. 4 In the center is the main instrument and control panel, and back of it is the base of the rectification column. At left, Harper Avis, plant superintendent, checks liquid nitrogen flowing into the thermos flask on floor. Partially seen at extreme left are the cold dryer unit and its control panel

"Then, without interruption to the customer's production requirements, one of our liquid oxygen trucks will tie a feed line into the customer's storage bank, and by using an evaporator and pump to convert the liquid oxygen into dry oxygen gas right on the truck, the customer's storage bank of tubes will be refilled. One such truck will carry a load of liquid oxygen equivalent to what it formerly required eight trucks to supply in oxygen gas. Yes sir, no interruption to the customer's production requirements, and no more hauling of empty cylinders or tubes back to the plant!"

These trucks are intended, of course, to supply only large industrial users of oxygen, and the first three of them are nearly completed. One truck will carry sufficient liquid oxygen to provide 90,000 cu. ft. of gas; the second will carry the equivalent of 150,000 cu. ft. of gas; and the third, a trailer unit, will carry the amazing equivalent of 280,000 cu. ft. of oxygen gas. This is American industrial ingenuity working in high gear—with a liberal dash of Texas know-how for good measure!

These liquid oxygen trucks will be used also to supply large and moderate-sized users of industrial oxygen, each of which are already—or soon will be—set up with a liquid oxygen storage tank and a converter unit to generate dry oxygen gas right on their own premises, for use as needed. With only a moderate-sized liquid oxygen storage tank, a plant so equipped is assured of ample and uninterrupted oxygen supplies at all times. Thus, large batteries of steel cylinders or tubes otherwise required are eliminated. In view of the present critical demands for steel, this is a direct contribution to the national defense effort.

NITROGEN GAS DEMANDS

Harry K. Smith, a director of the Houston Oxygen Co. and active in its management, explained, "Our new plant gives us ample production of high-purity nitrogen gas, heretofore in short supply at times. By using this inert gas to purge oxygen from pipe lines, tanks and ships carrying butane, gasoline, oil, chemicals, etc., the danger of explosion is minimized. This use is increasing every day.

"Large quantities of nitrogen gas are also used in fire-fighting, and in the manufacture of fire extinguishers of certain types. This inert gas actually smothers flames by preventing oxygen in the air from reaching the fire. It is also used as a shield against fire and explosion of chemicals due to decomposition in storage or while being processed.

"And it may surprise some to learn that nitrogen gas is now used to prevent rust and rot in the storage of iron and steel products, eggs—yes, that's right, *eggs*—and many other items. These uses, plus its use also in the manufacture of electric light bulbs, radio and television tubes, X-ray lamps, etc.—in addition to its extensive use in laboratory processes, testing and research—comprise a tremendous demand for pure nitrogen gas that must be supplied without interruption."

ARGON GAS USES

In answer to a question regarding the uses of argon gas, Mr. Herzstein replied, "Argon gas is extensively used in the welding of aluminum, copper, brass, tombac alloys, magnesium, stainless steel, and also in welding cast-iron and ordinary steels under certain conditions.

"Argon also is mixed with other gases for filling electric incandescent lamps as well as neon and fluorescent tubes, to obtain greater lighting brilliance and to greatly prolong service life. As far as we know, there are but three other producers of pure argon in the country from whom it can be purchased—none in the Southwest. So our new plant makes an important contribution in this respect too!"

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(*Continued from page 494*)

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Replacing Worn Plow Share Points

by L. M. Smith

WHEN a plow share point becomes worn so that the share no longer cuts the earth easily, it's time either to replace the share with a new one or to repoint the old share. A share can be repointed very satisfactorily using oxyacetylene welding and cutting equipment. The worn tip of the share is cut off using a cutting attachment or cutting blowpipe and a replacement tip is welded in place. Replacement tips can be obtained from welding suppliers and farm implement dealers. Repointing is actually a far more economical practice than replacing the share outright. In fact, four shares can be repointed for the cost of one new share.

To do the cutting, use the usual method for cutting steel. Either a cutting blowpipe or a cutting attachment for a welding blowpipe will do the job. Be sure to use the correct size nozzle and oxygen and acetylene pressures. See the instruction booklet that comes with your apparatus for this information. For best results, keep the ends of the pale blue core of the preheating flame about $^1/_{16}$ in. away from the metal. When a spot under the flames starts to melt, open the cutting-oxygen lever by slowly pressing down on the lever. As soon as

L. M. Smith is connected with the Linde Air Products Company, Milwaukee, Wis.

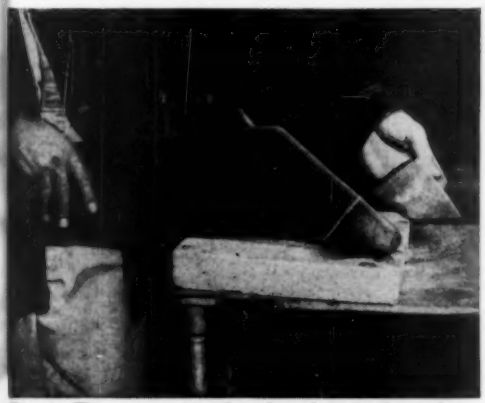


Fig. 1 The worn point of a plow share is shown here. Chalk-line marks the line of cut. Use cutting blowpipe or attachment for cutting

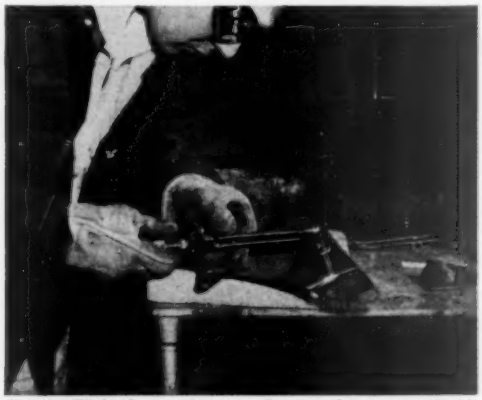


Fig. 2 With the cutting attachment the worn point is cut from the share. Follow the usual method for cutting steel

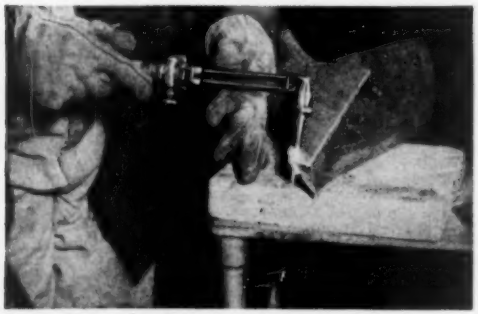


Fig. 3 Next, a bevel cut is made to prepare the share for welding. A corresponding bevel cut is made on the new plow point

Fig. 4 The share with the new point is shown here prior to welding. Note how the bevel widens toward the bottom of the share

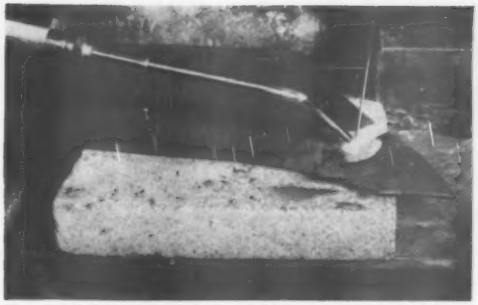


Fig. 5 Steel rod is used to weld on the new point. Be sure to melt the metal in the vee so that it forms a puddle with the molten welding rod. On extremely thick shares, a double bevel is recommended

Fig. 6 After wire-brushing, the completed weld will look like this. In time the raised surface of the weld will be worn flush with the share face. The point can also be hard-faced for long life

cutting starts, press the cutting lever all the way down. When the cut has gone all the way through, tilt the nozzle forward, a little bit in the direction of cutting. Use fusion welding to join the new point to the shave.

Sturdy, Lightweight Aluminum Gates and Ramps for Stockyards Are Heliarc Welded

LIGHTWEIGHT equipment that will stand heavy-duty service is a crying need for the stockyard. Aluminum gates and ramps have helped solve the twofold problem of providing equipment that is easy to move, but sturdy enough for long-term service with minimum repairs.

In the accompanying photographs, the aluminum gates and the portable cattle ramp have been fabricated of aluminum by Heliarc welding at the Pioneer Iron Works, Sioux City, Iowa. Heliarc welding equipment was provided by Linde Air Products Co., a Division of Union Carbide and Carbon Corp.

Fig. 2 Here the lightweight aluminum gates are in stockyard service

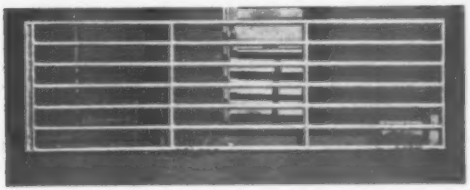


Fig. 1 This aluminum gate for use in stockyards, has been abricated by Heliarc welding at the Pioneer Iron Works, Sioux City, Iowa

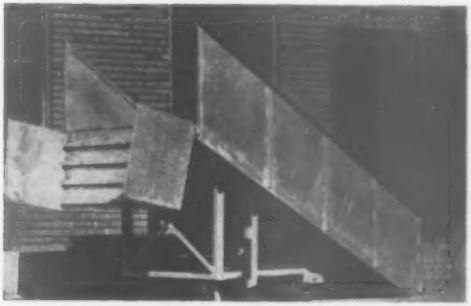


Fig. 3 This portable aluminum cattle ramp can be easily moved from one location to another. It was also fabricated by Heliarc welding

the AMERICAN WELDING SOCIETY

activities • related events

National Metal Exposition & Congress Philadelphia—October 20th to 24th

The National Metal Exposition for '52 is sold out!

Right to the last square foot of floor space originally laid out—and there's a growing list of unhappy firms who have previously exhibited waiting for a "break"—for a chance to grab off space somebody might not need. The show management is now checking over the Philadelphia Convention Halls and an additional exhibit area is being planned.

Weeks ago the Big Show was being harassed and crowded for space. The demand for space began early, refused to taper off, kept on building up until a new record for early sell-out was established.

Third Meeting of Board of Directors 1951–52 Year

The Board of Directors of the AMERICAN WELDING SOCIETY met in Parlor B, Hotel Claypool, Indianapolis, Ind., on Monday, Mar. 31, 1952, at 9:30 A.M., with the following present:

Members: C. H. Jennings, Chairman, F. L. Plummer, E. R. Seabloom, E. N. Adams, L. C. Bibber, T. J. Crawford, J. U. Durham, O. B. J. Fraser, R. S. Green, LaMotte Grover, T. B. Jefferson, H. E. Rockefeller, M. S. Shane, J. R. Stitt and E. O. Williams.

Staff: J. G. Magrath, Secretary, F. J. Mooney, Assistant Secretary, and Technical Secretary S. A. Greenberg (in part).

Guests: G. O. Hoglund, Chairman, National Program Committee; T. C. Fetherston and G. Van Alstyne, Members, Special Committee on Annual Meeting; and R. Yarbo, Vice-Chairman, Louisville Section. The following members of the Board of Directors of IAA were present to 11:15 A.M.: J. W. Dunham, President; L. W. Hench, Vice-President; H. F. Reinhard, Secretary; E. V. David, Treasurer; W. A. Brown, Jr., E. A. Daniels, A. J. Fausek, J. J. Lincoln, Jr., A. Lot, C. F. Smith, R. B. Swope. F. Fetherston, Secretary-Treasurer of the Compressed Gas Assn.

Call to Order

The meeting was called to order at 9:35 A.M. by Chairman C. H. Jennings who presided throughout the meeting.

Announcement

The Chairman announced that starting at 10:00 A.M the Board of Directors would hold a joint meeting with the Officers and Directors of the International Acetylene Assn. for discussion on collaboration of the two organizations in an activity in the spring of 1953 in southwest U. S.

Membership Classification Chairman

Chairman Jennings recommended to the Board of Directors approval of appointment of O. B. J. Fraser as Chairman of the Special Committee on Membership Classification, to replace J. B. Tinnon who resigned due to poor health.

Action: Upon motion, duly seconded, the Board of Directors so approved.

Renewal of WRC Contract

THE WELDING JOURNAL Committee recommended to the Board of Directors approval of renewal of the present agreement with the Welding Research Council for the publication of the *Welding Research Supplement*, such renewal to cover the years 1952 and 1953.

Action: Upon motion, duly seconded, the Board of Directors approved renewal of present agreement with the Welding Research Council for publication of the *Welding Research Supplement*, covering the years 1953 and 1954.

TAC Recommendations

The Technical Activities Committee of the SOCIETY recommended the following items for Board of Directors' approval:

(*a*) Appointment of S. A. Greenberg, AWS Technical Secretary, to serve as AWS Representative on ASA Sectional Committee Z48—Marking Compressed Gas Cylinders and ASA Sectional Committee A13—Identification of Piping Systems.

Action: Upon motion, duly seconded, the Board so approved.

(*b*) That Rules for Welding Piping in Marine Construction-Ferritic Alloy Steels be approved for publication as a tentative standard of the SOCIETY.

Action: Upon motion, duly seconded, the Board so approved.

(*c*) The adoption of the revisions to the Standard Rules for Field Welding of Steel Storage Tanks to be incorporated in a 1952 edition of this standard and published as a full standard of the SOCIETY.

Action: Upon motion, duly seconded, the Board so approved.

(*d*) Proposed revisions to AWS-AWWA Standard Specifications for Elevated Steel Water Tanks, Standpipes and Reservoirs.

Action: Upon motion, duly seconded, the Board so approved.

(*e*) The adoption of Tentative Specification for Copper and Copper-Alloy Welding Rods as a joint tentative standard of AWS and ASTM.

Action: Upon motion, duly seconded, the Board so approved.

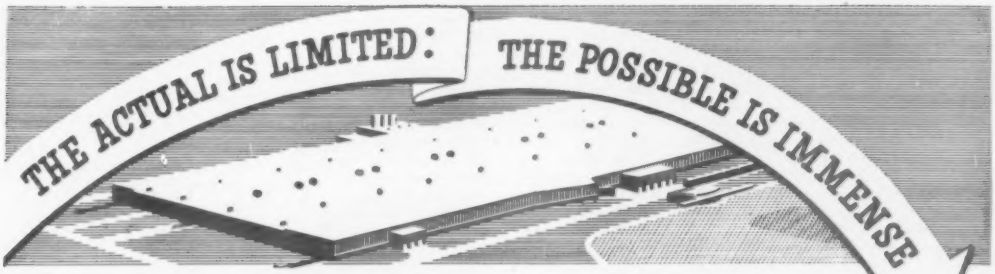
Sales Promotion of AWS Publications

J. R. Stitt stated that at present the SOCIETY has 120 Sustaining Members and 163 Supporting Companies. Sustaining Members automatically receive complete set of codes upon joining the SOCIETY and new codes as published. He suggested that in an effort to promote the sale of the SOCIETY's codes, standards and specifications, Supporting Companies and individuals interested should be approached to determine if they would be interested in securing all AWS published codes at a special price. Further, new codes as published could be automatically sent to Supporting Companies on a complimentary basis. In this way, each Supporting Company would be acquainted with the code and would be encouraged to place quantity order purchase at list price for code, less quantity order discount. Mr. Stitt pointed out that the orders received would more than justify the expense of complimentary mailing of the code to Supporting Companies. Members of the Board, realizing that there are many items to be considered, such as special price for published codes, whether members and nonmembers should be charged alike, etc., authorized the Chairman to appoint a Special Committee to review the proposed plan and submit its recommendations to the Board of Directors at a subsequent meeting.

Action: Chairman Jennings appointed a Special Committee on Dissemination of Technical Codes, Standards and Specifications, consisting of S. A. Greenberg, *Chairman*, J. R. Stitt, I. Morrison and F. J. Mooney, members.

TAC Members-at-Large

J. R. Stitt stated that the Board of Directors should consider a change in the SOCIETY's By-Laws regarding appointment by the President of not more than three Members-at-Large to serve on the Technical Activities Committee for a one-year period. It was his feeling that instead of appointing three Members each year to serve for a one-year period, it would be advisable to appoint one Member each year to serve for a three-year period. As it now stands, when the Members are acquainted with the activities of TAC their term of office is near its close. By appointing one Member each year, to



NEW LINCOLN PLANT CREATED BY INCENTIVE-INSPIRED CO-ACTION IN DEVELOPING POSSIBILITIES IN PRODUCT

© LE Co. 1952

WELDED STEEL SIMPLIFIES CONSTRUCTION IMPROVES PERFORMANCE, CUTS COST 33%

By **Russell M. Roberts,** Chief Engineer,
Parks Woodworking Machine Company, Cincinnati, Ohio

Changing over our band saw frame to welded steel design has simplified many production problems while cutting costs by one third.

The original cast construction (Fig. 1) called for machining a complicated casting on which foundry rejections were common. The present welded steel design utilizes simple square tubing, sawed to size, clamped in a plain fixture and butt welded. The efficient use of steel has cut weight by 37% while increasing strength and rigidity.

An added benefit, made possible with welded design, now permits independent leveling of the work table that formerly could be accomplished only through a major adjustment of the frame itself.

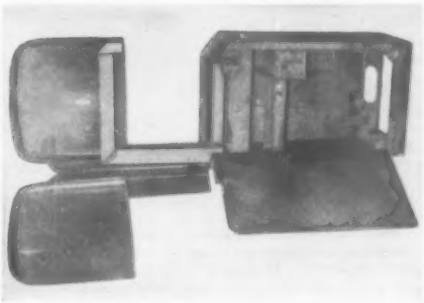


Fig. 4—All Welded Steel Frame *for the Parks Woodworking Machine Co., Cincinnati, Ohio. Sides are brake formed from 12 gauge metal.*

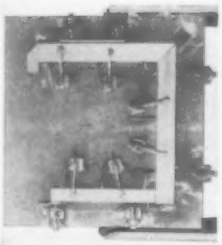


Fig. 3—Simple Jig *for welding square steel tubing components consists of clamps and locating pads.*

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Complete training course for designers and production engineers now available for presentation in your plant. Send for complete details.

PROPER DESIGN IN WELDED STEEL ALWAYS IMPROVES PRODUCT, LOWERS COST

Fig. 1—Original Construction— *Machine bracket formerly weighed 56 pounds, was difficult to cast, high cost incurred from excessive rejects.*

Fig. 2—Welded Steel Design *is stronger, more rigid yet weighs only 35 pounds. Weldment costs 33% less than original casting. Eliminates considerable time in machining and assembly.*

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serve for a three-year term, he would become better acquainted with the activity as time progresses and could more efficiently serve the Committee. After discussion, members of the Board approved the proposal in principle and authorized the Chairman to appoint a Special Committee to further study this item and submit its recommendations to the Board of Directors at a subsequent meeting, the Special Committee to consist of the Chairman of TAC and two members currently serving on the Board of Directors.

Action: Chairman Jennings appointed a Special Committee on TAC Appointments by the President, consisting of E. R. Seabloom, *Chairman*, C. D. Evans and T. B. Jefferson, members.

1952 National Fall Meeting Budget

The Assistant Secretary distributed proposed budget of income and expense for the 1952 National Fall Meeting. This budget has met with the approval of the National Convention and Finance Committees.

Action: Upon motion, duly seconded, proposed budget of income and expense for the 1952 National Fall Meeting was approved as submitted.

Reserve Funds Committee Recommendation

The Reserve Funds Committee, at a meeting held on Feb. 14, 1952, voted unanimously to recommend to the Board of Directors for approval that the By-Laws of the Society be amended to authorize the purchase of securities as permitted by Trust Funds and as approved by the State of New York. O. B. J. Fraser, Chairman of the Reserve Funds Committee, stated that the Assistant Secretary contacted the Society's attorney and auditors as to proper wording in the Society's By-Laws to accommodate this change. Both were in agreement that should the Board of Directors approve such action, then Article XII, Section 14, of the Society's By-Laws could properly be worded in part as follows:

Proposed Wording: Funds turned over to this Committee by the Board of Directors shall be in its custody for safekeeping and the Committee is authorized to hold these funds in cash and/or investments approved by the State of New York for fiduciaries as permitted by Section Twenty-One of the personal property law of the State of New York.

Present Wording: Funds turned over to this Committee by the Board of Directors shall be in its custody for safekeeping and the Committee is authorized to hold these funds in cash and/or investments approved by the State of New York for Savings Banks and Insurance Companies.

Action: Upon motion, duly seconded, the Board of Directors approved purchase of securities as approved by the State of New York for fiduciaries as permitted by Section Twenty-One of the personal property law of the State of New York and referred this action to the Constitution and By-Laws Committee for necessary change in the Society's By-Laws. Also, for that Committee to receive official confirmation from the Society's attorney regarding proper wording in the By-Laws.

Full-Time Membership Secretary

I. Morrison, Chairman of the National Membership Committee, in a communication to the Board of Directors recommended that the Board give serious consideration to the employment of a full-time Membership Secretary whose task would be to promote the sale of memberships. He stated that as a volunteer his efforts this year will probably realize a net increase of 500 members over last year. 500 members represent $7500 in added revenue and a Membership Secretary devoting all his time to such an activity should show a result of at least twice this year's figure, as well as add immeasurably to the stature and growth of the Society. Discussion ensued resulting in the attending members deferring action on Mr. Morrison's proposal until the Society's Secretary could accumulate figures regarding anticipated costs for the employment of a Membership Secretary and additional clerical expenses that may be involved.

Welding Clinics

The Secretary advised that "Welding Clinics" are increasing in number. These clinics are frequently proprietary sponsored by some large metal supply organization or equivalent. Such organization invites specific welding equipment manufacturers, with whom it has business arrangements, to exhibit their products in a warehouse or other location which is the property of the sponsoring supply company. In such instances, the invitations sent out to

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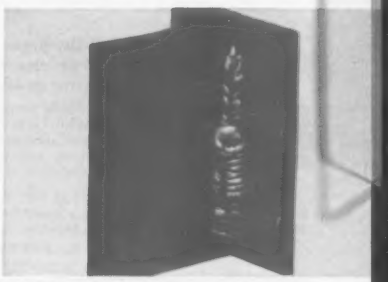

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welding equipment manufacturers are not in the order of open invitations to all, but rather specific invitations to certain companies only. Invitations have been extended to AWS to man a booth at such activities for the purpose of securing memberships. The Secretary requested the Board to decide whether they wish to institute a ruling regarding the SOCIETY's policy in connection with such activities. The Secretary advised that when such activities have been proposed, he has first put up the proposition of participation to the Section Officer group whereat the activity is held. He has cautioned the Section Officer group that inasmuch as these are proprietary activities, AWS is present on the basis only of a participator as far as display is concerned and, under no conditions, can AWS or its Section sponsor such an activity. He observed that sponsorship was indicated to some people in the instance of a recent activity at Buffalo due to the fact that the AWS Niagara Frontier Section held its monthly meeting on the premises of the proprietary exhibitor. This was taken by some to indicate that the whole activity was sponsored by the Local Section. Such was not the case. He advised that, in the future, recommendations to the Sections would also observe that they should not hold a regular Section meeting on the property of the exhibitor should such be misconstrued as sponsorship. He pointed out that AWS participation as an exhibitor at the Buffalo Welding Clinic had resulted in a number of new memberships in the SOCIETY and a great deal of good will. He felt that comparable activity at other welding clinics would result in the same. In discussion, it followed that the greater number of the Board members were in agreement with the advantages of AWS participation as long as it or its Section did not sponsor the activity. It was decided that no ruling should be instituted in regard to this activity, but rather that the Secretary should proceed in the future on the pattern employed in the past.

By-Law Revisions

The Constitution and By-Laws Committee submitted to the Board of Directors for approval suggested By-Law revisions to provide for Student Members and Student Chapters in trade schools. The proposed revisions indicate annual dues rate for Student Members of $5.00, instead of the present $3.00. Prof. R. S. Green voiced disapproval stating that by so doing we would not be encouraging Student Memberships. In general, the Board felt that this matter had been adequately discussed at a meeting of the Finance Committee and at the previous meeting of the Board of Directors and that, therefore, the recommendation should stand.

Action: Upon motion, duly seconded, members of the Board approved By-Law revisions as submitted by the Constitution and By-Laws Committee for Student Members and Student Chapters in trade schools, with the following changes:

Article I, Section 2D—First sentence, delete words "taking a course beyond the terminal level." Third sentence, change words "the AWS fiscal year" to "his membership anniversary."

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Membership Billing

In that the ruling of the Board of Directors in the order of change of By-Laws was to the effect that memberships received during the month shall not become effective until the close of the month and that Headquarters in following through has notified the member by post card that his application was received and then at the beginning of the month following forwarded his membership card, it was determined that regardless of this ruling it would be better if the membership card was forwarded to the member as quickly as possible after receipt of application but that, in the order of the By-Laws, the membership for the individual would not become effective until the last day of the month in which it was received.

Secretary's Note: Hereafter, included with each membership card, there shall be a mimeographed statement to the effect that the new member's membership year, which includes benefits and privileges of membership, begins one year prior to the expiration date shown on his membership card.

Next Board Meeting

The next meeting of the Board was tentatively set for Aug. 26, 1952, to be held in New York City.

Carrying the Message to Garcia

So that the message that AWS has to give may better reach those who should be

AWS Members, National Headquarters has had designed and fabricated a display unit with background which may be set up at National Meetings, Exhibits, etc. It is of light weight aluminum framing with background draped in blue and gold. The counter is similarly decorated. The placards tell how all interested in welding benefit from AWS membership. Fluorescent and beam spotlights and a translucent AWS Emblem panel make for a very complete, compact and attractive display.

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GENERAL ELECTRIC

645-55

Third Conference on Electric Welding an Outstanding Success

The Third Conference on Electric Welding got under way with a flying start on Wednesday, April 16th, in Detroit, Mich., at the Rackham Memorial Bldg. This activity, of increasing popularity and interest, is a bi-annual event sponsored by the American Institute of Electrical Engineers in cooperation with the AMERICAN WELDING SOCIETY and the Industrial Electrical Engineers' Society of Detroit. The Conference duration of three full days' events, April 16th, 17th and 18th, provided an excellent opportunity for the electrical and welding industries' prominent engineers and authorities to join in meeting for review and discussion of Quality Control, Instrumentation, Power Supply and Resistance Welding as well as, through the cooperation of the AMERICAN WELDING SOCIETY, Detroit Section, to review the latest developments in Fundamental Arc Research and Arc Welding; one complete session, morning or afternoon, being devoted to each of these interests and subjects.

In addition, the AMERICAN WELDING SOCIETY, Detroit Section, sponsored, on Thursday and Friday evenings, a Demonstration Session of electric welding techniques and equipments. This activity featured techniques, processes and devices, equipment or machines that essentially are *new*, having been developed or introduced to industry during the past two years, and since the preceding Conference in 1950. On Friday evening, April 18th, the AMERICAN WELDING SOCIETY, Detroit Section, in conjunction with the Conference activity, held its monthly general meeting. Walther Richter, Consulting Engineer of Milwaukee, Wis., addressed the meeting on the subject of "Instrumentation from the Viewpoint of the User."

The Welding Conference Activity was organized under the direction of C. N. Clark, Chairman, Conference Committee, and an Executive Committee composed of E. J. Limpel, Chairman, Papers Committee; C. M. Rhoades, AWS, Chairman, Publication Committee; J. S. Francis and S. H. Brams, AWS, Co-Chairmen, Publicity Committee; Dr. A. DiGiulio, AWS, Chairman, Demonstration Committee; G. W. Garman, AWS, Conference Treasurer; J. F. Deffenbaugh, AWS, Secretary; Keith Sheren, AWS, Chairman, AMERICAN WELDING SOCIETY, Detroit Section; and V. H. Chisholm, AWS, Chairman, Industrial Electrical Engineering Society of Detroit.

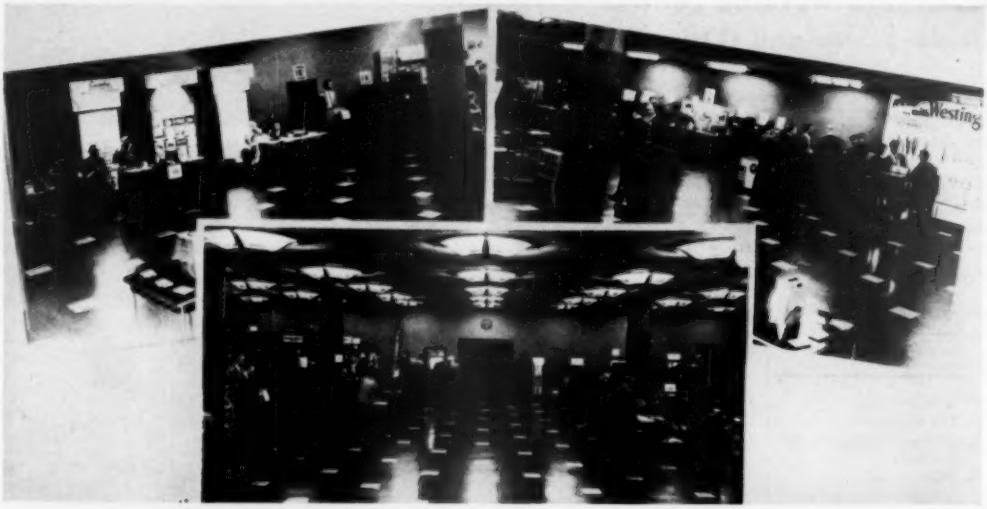

Photo in Live Demonstration Hall in front of AWS Booth

Front row (left to right): Jos. G. Magrath, National Secretary, AWS, New York, N. Y.; Wm. P. Kramer, Chairman, Local Publicity Conference Committee, National Electric Welding Machine Co., Detroit, Mich.; Dr. Armand DiGiulio, Chairman, Live Demonstration Committee, Consulting Engineer, Detroit, Mich.; C. N. Clark, Conference Chairman, Duquesne Light Co., Pittsburgh, Pa.; S. W. Luther, Chairman, Local Conference Committee, Detroit Edison Co., Detroit, Mich.; G. W. Garman, Conference Treasurer, General Electric Co., Detroit, Mich.; Keith Sheren, Chairman, Detroit Section, AWS, Taylor-Thompson Machinery Co., Detroit, Mich.

Back row (left to right): E. G. Petrini, Conference Registrant, McNeil Machine & Engrg. Co., Akron, Ohio; Frank Frudd, AWS Committee, Ace Welding Supply, Inc., Detroit Mich.; Bob Hawks, Detroit Section Membership Chairman, Ace Welding Supply, Inc., Detroit, Mich.; Jos. J. Sennello, Conference Registrant, Continental Can Co., Chicago, Ill.

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The Demonstration Session was arranged and supervised by an all-AWS Committee consisting of Dr. A. DiGiulio, Chairman, and G. W. Garman, J. M. Johnston, J. F. Randall and L. A. Strobel, Members.

Serving on other important Standing Committees, in various capacities of Vice-Chairmen, Secretaries and Members, were the following prominent AWS Members: S. H. Brams, T. F. Ellis, A. C. Good, Julius Heuschkel, S. C. Hinds, A. H. Holm, A. W. Kelsey, W. P. Kramer, R. J. Krieger, C. R. Molenar, W. N. Moore, L. C. Poole, J. F. Randall, M. S. Shane, H. P. Sparks, C. B. Stadum, P. Strother, R. E. Young and Myron Zucker.

The Conference was opened by Keith Sheren, Chairman of the AMERICAN WELDING SOCIETY, Detroit Section, who introduced Charles H. Jennings, National President of the AMERICAN WELDING SOCIETY, observing his long and outstanding record of achievements in the AMERICAN WELDING SOCIETY and the welding industry, such, in his year of presidency, rightfully giving him the title of "Mr. Welding, 1952." President Jennings addressed the assembly, welcoming all Members of the three participating Societies and their guests to the three-day activity of the Third Conference. C. N. Clark, Conference Chairman, followed with an outline of the scope and objectives of the activity and a brief review of the program. Immediately thereafter, the Conference was under way to a well-attended series of sessions. For the three-day technical sessions there was a registration of just over five hundred from all sections of the United States, coast to coast, from Canada and from England, as well, in the person of Guy Cubitt-Smith of Crompton Parkinson Ltd.

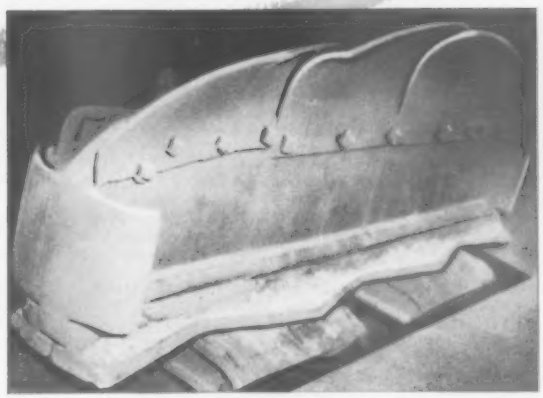
Among other prominent Activity Members of the AMERICAN WELDING SOCIETY registrants were F. A. Bodenheim; F. L. Brandt; J. H. Blankenbuehler; D. H. Corey; T. J. Crawford, District Vice-President, AWS; F. H. Dill; S. A. Greenberg, Technical Secretary, AWS; W. F. Hess, Past-President, AWS; H. L. Herbst; J. G. Magrath, National Secretary, AWS; R. C. McMaster; M. S. Noyes; C. C. Peck; A. L. Pfeil; O. J. Ryder; E. A. Sirabian; W. F. Savage; R. E. Somers; H. W. Stieglitz; J. B. Welch; L. E. Wagner and G. K. Willecke.

The AWS-sponsored Demonstration Session was held in the Exposition Room of the Rackham Memorial Bldg. Demonstrations, with exhibits of the required equipment, were provided by the Aluminum Company of America, General Electric Co., Industrial Electronics, Inc., Jered Engineering and Manufacturing Co., P. R. Mallory Co., National Time and Signal Corp., C. C. Peck Corp., Progressive Welder Co., Robotron Corp., Satullo Co., Roy Smith Co., Square D Co., Thomson Electric Welder Co., Welding Equipment and Supply Co., Weltronic Co., and the Westinghouse Electric Corp.

The activity came to a close on Friday evening at a session of the Detroit Section of AWS. Walther Richter, Consulting Engineer, Milwaukee, Wis., gave a most interesting talk, spiced with sharp and to-the-point humor, on "Instrumentation from the Viewpoint of the User."

These Hard-Faced Coke Pusher Shoes Lasted Over Two Years

STEEL SHOES WORE OUT IN TWO MONTHS



Riding over the coke-covered floor of an oven wears out plain steel pusher shoes in only two months. Hard-faced shoes have lasted at least two years, despite the severe abrasion, heat, thermal shock, and erosion involved in operation. With minor repairs, the hard-faced shoes can be used for another two or three years.

HAYNES STELLITE No. 1 hard-facing rod was selected to protect these shoes because it is hard enough to resist abrasion from the coke particles and the lining of the oven floor. It does not chip or spall under the thermal shock of returning from 1800 deg. F. in the oven to atmospheric temperatures.

There is a complete line of HAYNES hard-facing materials to choose from. Each is particularly suited to combat certain conditions of wear, heat, corrosion, or erosion. For a quick summary of the properties and forms of the various HAYNES rods, write for "HAYNES Hard-Facing Materials Data."

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Chicago — Cleveland — Detroit — Houston
Los Angeles — New York — San Francisco — Tulsa

Photos on Spot Welding Aluminum and Its Alloys Symposium

Figure 1

Photos Courtesy, Welding Engineer

Figure 2

Reading *left to right*—(*back row*): J. J. MacKinny, W. J. Wilson, Julius Heuschkel, Floyd Matthews, G. O. Hoglund; (*front row*): I. W. Johnson, Fritz Albrecht and S. A. Greenberg

Symposium on Spot Welding Aluminum & Aluminum Alloys

One hundred and thirty-one welding engineers from every part of the United States attended the Symposium on Spot Welding of Aluminum and Aluminum Alloys sponsored by the AWS Resistance Welding Committee at the Hotel Knickerbocker in Chicago on March 11th and 12th. Figure 1 shows a representative portion of the audience.

W. J. Wilson of Kaiser Metal Products, who is Chairman of the Subcommittee on Aluminum of the AWS Resistance Welding Committee, presided as Chairman.

The program was opened by an address of welcome by Julius Heuschkel of the Westinghouse Electric Corp. and Chairman of the AWS Resistance Welding Committee.

G. O. Hoglund of the Aluminum Company of America led the discussion on the base metal properties of aluminum and its alloys from the standpoint of weldability.

A discussion of Surface Preparation of Spot Welding of Aluminum and Aluminum Alloys was led by Fritz Albrecht of the Glenn L. Martin Co.

Welding Machines and Controls for Spot Welding Aluminum were discussed under the leadership of I. W. Johnson of the General Electric Co.

Welding Techniques were discussed under the leadership of J. J. MacKinney of the Budd Co.

Typical Welding Schedules were distributed and the discussion of welding schedules for spot welding aluminum using different types of equipment was led by Floyd Matthews of the Boeing Airplane Co.

The above speakers are shown in Fig. 2.

All those present participated very actively in the discussion and it was unanimously agreed that the exchange of ideas afforded was invaluable.

May Tell Industry More About Boiler Plate Steel

University of Illinois engineers are blowing bulges in boiler plate and are making $^3/_8$-in. thick steel vibrate almost like rubber.

This is part of research which may save tons of steel and thousands of dollars for American industry. The object is to produce better boilers, refinery equipment, storage tanks and other steel containers involving high pressures.

The Pressure Vessel Research Committee of the Welding Research Council is sponsoring the project to set new design standards. Now these are made of very thick metal. Engineers feel that thinner metal could do the job, but the standards cannot be changed without more knowledge about new alloy steels.

Prof. Thomas J. Dolan and Prof. Cletus E. Bowman are working on the project at Illinois. They have built a machine which in 3 hours can subject steel to repeated stresses equaling 40 or more years of service life.

Steel plates 9 by 17 in. in size are clamped in the machine. Oil pushes against one side of the plate with as much as 2500 lb. pressure per square inch. The force against that one piece of steel may be 190 tons.

The pressure is automatically varied, 75 or 100 times a minute, and as the oil surges against the boiler plate it pulses as if it were rubber. A permanent bulge of as much as half an inch may be made in the steel plate.

The two-way stretch of the pulsing bulge strains the metal just as if it were part of a boiler. Hundreds of these tests can be made for less cost than even a small boiler. If a crack begins, the machine automatically stops.

The Illinois engineers have spent most of the past year perfecting their equipment. They expect to spend one or two years making the many tests necessary for new design standards.

At the same time the industry is sponsoring similar tests, though at a slower rate and on a more restricted scale, in a commercial laboratory. Results will be cross-checked.

When final data are assembled and tentative new design standards are made, the industry plans demonstration tests—and a third check—by building and testing several full-size boilers.

(From *University of Illinois Alumni News* of April.)

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NEWS OF THE INDUSTRY

Struthers Wells Installs New X-Ray Machine

It has been announced by John T. Dillon, President, that a new X-ray machine of 400,000 volt capacity has been installed at the Titusville Forge Division of Struthers Wells Corp.

This unit was installed under the supervision of Pittsburgh and Erie engineers of the General Electric Co. X-ray Department.

The main application for this high capacity unit will be the radiographic examination of larger vessels with heavier sections than can be penetrated with the lower voltage equipment now in use. This unit will permit the examination of steel plate up to 5 in. in thickness.

The high voltage feature, which results in X-rays of extreme penetration and short wave length, also makes it possible to X-ray products of widely varying thicknesses and densities with a single exposure. This is due to the fact that short wavelength X-rays will more easily pass through a wider range of thicknesses and densities and thus have more latitude than do longer wave-length rays produced by X-ray equipment of lower voltage. They also permit the making of X-ray films with finer shading, revealing details not otherwise seen on X-ray films.

Higher voltage X-ray equipment provides, in addition, the advantage of greatly reducing the time required to make an X-ray.

The X-ray unit is so mounted that it can be moved into any desired position, and may be used to radiograph any type vessel or heavy weldment produced in this plant.

ASTM Changes 1953 Annual Meeting Date

The American Society for Testing Materials announces that it has changed the date of its Annual Meeting for 1953 from June 22nd to 26th to June 29th to July 3rd. As already announced, the meeting will be held at Chalfonte-Haddon Hall, Atlantic City, N. J. This change has been made at the request of the Departments of Commerce and State of the Federal Government and specifically of the United States National Commission of the Pan American Railway Congress Assn. Arrangements have been made by the Government to hold the Eighth Pan American Railway Congress in Washington and Atlantic City over the period from June 12 to 25, 1953. This is the first of these congresses to be held in the United States, and to accommodate so large a group the complete facilities of the beachfront hotels at Atlantic City were desired.

SESA 1952 Spring Meeting

The Society for Experimental Stress Analysis announces that it will hold its 1952 Spring Meeting on May 14th, 15th and 16th, at the Hotel Lincoln, Indianapolis, Ind. The meeting will feature a number of panel discussions on various phases of experimental stress analysis.

Training Program

A comprehensive sales training program to develop well-informed salesmen-technicians, able to cope with customers' problems, has been undertaken by the Welding Products Division of A. O. Smith Corp., Milwaukee, Wis.

The program is designed to give trainees a broad understanding of welding techniques and applications without their having previous welding knowledge.

First part of the course is an eight-week period spent in learning the techniques of electrode manufacturing.

Following this, the trainees spend 12 weeks in the Welding Research Laboratory where they observe all types of welding used by A. O. Smith, and are required to pass regular tests as qualified welders.

The third segment of the program places trainees in the welding equipment manufacturing plant where they learn about the construction and use of A. O. Smith welding machines.

Following these operational phases of his instruction the students will work in the divisional sales office at Milwaukee becoming familiar with sales correspondence and order service and developing knowledge of what is involved in servicing a customer.

The course is completed with each trainee serving a six-month period in the field is a junior salesman, working under more experienced men.

Annual Meeting of the American Institute of Steel Construction

The fourth annual American Institute of Steel Construction National Engineering Conference was held on April 23rd and 24th at the Hotel Commodore.

Over 200 attended with staff engineers present from a majority of the 273 AISC member companies. Representatives of the Canadian Institute of Steel Construction attended, as did also engineering professors from various colleges.

On Wednesday morning papers were presented on "Design and Construction of United Nations General Assembly Building" and "Lever House—A Lightly Loaded Two-Story Steel Frame." The afternoon was devoted to a panel discussion on the AISC's Research Program.

On Thursday morning a panel discussion covered "Problems of Welded Fabrication." The afternoon consisted of informal discussions on current engineering topics.

The district engineers and engineering staff of AISC held their annual meeting April 21st, 22nd and 25th at AISC headquarters, 101 Park Ave.

The AISC engineering department continuously conducts research on subjects pertinent to structural steel fabricators and prepares textbooks, manuals and specifications, as well as technical papers of interest to the engineering profession.

The District Engineers in 15 areas work with member companies, public officials, architects and engineers promoting the use of structural steel.

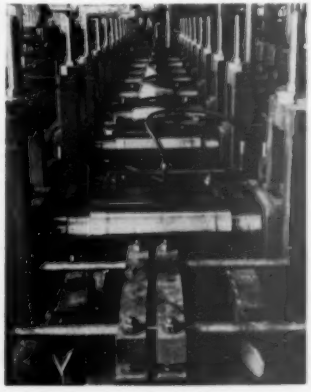
The Welding Research Council is cooperating with the Institute on research programs dealing with rigid frame construction. In this research work carried on at Lehigh University the investigation covered the behavior of columns, beams, joints and their assembly in a welded rigid frame structure from the elastic range into the plastic range.

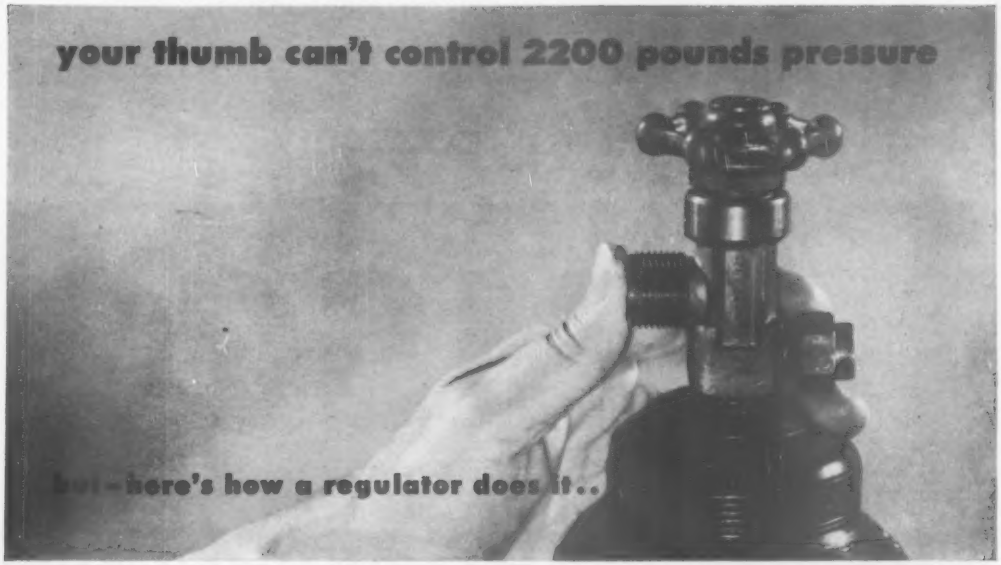
Ford Completes Two New Welded-Tube Mills

After nearly three years of engineering research and planning, Ford Motor Co. has completed two of industry's most modern welded steel tube processing operations which are producing 180 ft. of tubing a minute.

Designed for quick conversion to defense production of welded tubing up to 5 in. in diameter, the mills are located at the company's Mound Road plant, near Detroit.

One is nearly 400 ft. long and turns out tubing for axle housings at a rate of 75 ft. a minute. The other, 175 ft. long, is producing 105 ft. of tubing a minute for drive-





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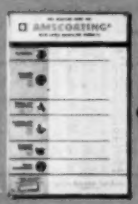

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The manufacturing procedure of both mills is approximately the same and begins with the automatic unwinding of coiled steel from huge drums. Steel stock enters the loading end of the mill and is gradually formed into tubular shape by a series of parallel rollers.

The tube is then welded automatically and the flash removed.

Following this, the tube stock is cut to desired length by a process that virtually eliminates waste.

Tube stock then is moved automatically to annealing furnaces and transported to other manufacturing buildings to be processed into rear-axle and driveshaft assemblies.

Turbine-Condenser Welding Time Cut 70%

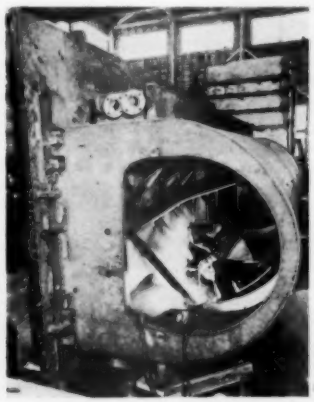
Welding time on large turbine condensers at the Sunnyvale, Calif., plant of the Westinghouse Electric Corp. has been cut 70% by positioning the condensers. Originally, all welding operations were performed with the condenser in one position. The results were satisfactory, but the all-position welding required was time consuming.

The condenser now is positioned first on one side, and then the other, thus eliminating all vertical and overhead welding. The condenser, plus the strongback weighing about 35 tons, is positioned with an overhead crane having an auxiliary hook to hold the condenser in its unbalanced position while cribbing and blocking is moved into place.

By positioning the condenser for downhand welding, larger electrodes can be used, and fewer passes are needed per joint. This means not only a higher deposition efficiency, but less time spent cleaning away slag between passes.

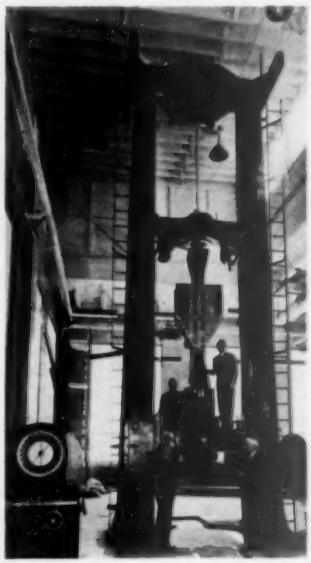
In addition to the time saved, the welding job has a more uniform appearance throughout, and some of the cramped and uncomfortable positions of the welders are eliminated, making the job less fatiguing.

The time spent in positioning the condenser is negligible compared to the more than 500 welding hours saved on each unit.



600,000-Lb. Capacity Welded Testing Machine

First Baldwin testing machine of 600,000 lb. capacity to have columns and base made as weldments was installed recently in the new Structures Laboratory at Purdue University. Baldwin-Lima-Hamilton Corp. has revised design of all testing machines of this type to welded construction instead of steel castings. Welds are so well finished on the exterior that joints are indistinguishable from parent metal. Smooth, flat surfaces of steel plate improve the appearance of the machine.



The machine will be used mainly for research on concrete and steel structures. Most of the work will be done by graduate students at Purdue under the direction of faculty members. Sponsors for testing projects include the Association of American Railroads, Column Research Council of the Engineering Foundation, and Research Council for Riveted and Bolted Structural Joints.

Lincoln's System for Welded Design

To convince the Army to buy 14 welding machines in 1917 The Lincoln Electric Co. agreed to establish a welding school at its factory in Cleveland, Ohio, to teach soldiers how to weld. The school is still operating and has graduated over 35,000 welders for industry.

Today Lincoln reports that it is starting an entirely different type of training program for engineers to help industry reduce the basic cost of making machinery up to 50%, and reduce the weight as much as 30%. Lincoln engineers claim that

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A Lincoln field engineer explains to industrial engineers how costs and weight can be reduced with the welded design system developed and taught by Lincoln engineers in special evening courses

they have developed new information never before available to industry which constitutes a new approach to the use of welding in the design of all types of machinery. This new information supposedly allows manufacturers of machinery to take full advantage of the superior properties of steel as a material. Long involved calculations ordinarily required in designing are either shortened or eliminated.

The training program is being made available in principal cities throughout the country by especially trained field engineers. It is open to all qualified engineers engaged in manufacturing machinery who are interested in reducing manufacturing costs, saving steel and improving product performance. It is intended for all manufacturers regardless of whether or not welding is being currently used.

Agriculture Meets Welding Industry

The top young farmers of the nation are the national officers of the Future Farmers of America Organization. They are selected in competition among the 300,000 members. On a recent good-will tour of major industrial centers in the East and Midwest they visited leading business organizations who sponsor the FFA, including The Lincoln Electric Co.

The accompanying photograph shows A. F. Davis, Vice-President of Lincoln Electric Co., explaining a wall diagram of the company's new $10,000,000 plant for making welding machines and electrodes.

Left to right: Dr. W. T. Spanton, national FFA adviser of Washington; Charles Ocker, Cameron, Mo.; Duane Drushella, Scio, Ore.; Gerald Reynolds, Corfu, N. Y.; Dallas High, Ohio City, Ohio; John Folts, Bremen, Ohio; Billy Howard, Plains, Ga.; Donald Staheli, Hurricane, Utah

Employment Service Bulletin

V-268. Welding Research Engineer. A company who has pioneered in welding and is considered by industry as a leader in the field has an excellent opportunity for an engineer with welding and metallurgical background. Preferable some experience in furnace brazing of metals in controlled atmospheres. This is an interesting position in the development of welding application to diversified projects. Location, Midwest. Excellent starting salary.

V-269. General Welding Engineer. Opportunity in research and development welding laboratory for a graduate engineer. Welding experience is preferred but not necessary. Duties include research and development in welding processes and application to new and present products. We are a multiplant operation with a diversified line of products. If you are interested in doing welding research we invite your inquiry. Midwest location.

V-270. Welding Engineer. Knowledge of resistance, induction, arc and gas welding required on plate, stainless steel and aluminum. Long-range program, working with new, modern equipment in new plant, salary commensurate with ability. Also need foreman and experienced welders. For further details, write David Brauer, Personnel Manager, Daystrom Instrument Division, Archbald, Pa.

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PERSONNEL

Dr. G. V. Slottman Elected a Vice-President of Air Reduction Co., Inc.

Directors of the Air Reduction Co., Inc., have elected George V. Slottman as a Vice-President. He has been the company's director of research and engineering since February 1949, and will continue in charge of that activity.

Dr. Slottman, a native New Yorker, was graduated from Massachusetts Institute of Technology in 1925. Two years later, he received his Ph.D. from the University of Berlin, and returned to M.I.T as a professor of chemical engineering.

George V. Slottman

From 1930 to 1934, Dr. Slottman served as chief combustion engineer and iron works manager for the United Steel Companies, Ltd., Sheffield, England. He joined Airco in 1934, and since that time has served as manager of the General Technical Sales Department, technical assistant to the Vice-President and director of research and engineering.

Dr. Slottman has been closely associated with Airco's development and introduction of steel-making processes using oxygen for both combustion purposes and as a chemical reagent. He has also authored a number of articles published on these topics, and was co-author of "Oxygen Cutting," the most comprehensive book of its type published in recent years.

Charles Ness Receives the Morehead Medal

The 1951 James Turner Morehead Medal of the International Acetylene Assn. has been awarded to Charles Ness, Superintendent, Acetylene Research Laboratory, The Linde Air Products Co. The award was made to Mr. Ness for his many contributions to design for safety, efficiency and economy, in the generation, pipeline distribution and packaging of acetylene.

Charles Ness

The presentation was made by C. E. Monlux, Past-President and Director of the International Acetylene Assn. and Vice-President, The Linde Air Products Co., at the opening session of the Convention of the International Acetylene Assn. at the Claypool Hotel, Indianapolis, Ind., on March 31st.

The Morehead Medal is awarded annually by the Association for outstanding work in advancing the industry or the art of producing or utilizing calcium carbide, its derivatives and allied products, the most important of which is the gas—acetylene.

Through the generosity of the Honorable John Motley Morehead, the yearly award of the medal has been made possible. The practice of awarding the medal was established in 1922 to honor his father, James Turner Morehead, who was responsible for the experiments leading, in 1892, to the discovery of the electric furnace method of producing calcium carbide. Since then the medal has been awarded annually.

Charles Ness was born July 4, 1891, in Chicago, Ill. He attended the Chicago Public Schools and then entered Armour Institute of Technology, known today as Illinois Institute of Technology, in Chicago. He graduated in 1912 with a B.S. in Chemical Engineering.

From 1914 to 1917 he served as gas tester for the City of Chicago and during World War I was in charge of the U. S. Army Ordnance Laboratory at Chicago.

In 1919 Mr. Ness joined The Linde Air Products Co. and was assigned to research work at their Buffalo, N. Y., laboratories. There his early work was concerned with filler materials for acetylene cylinders. He then became active in the design and operation of acetylene generators and acetylene distribution equipment and joined the Acetylene Research Division when it was established in 1922, in Indianapolis.

Under his direction a monolithic type filler was approved and put into production. His interest in acetylene cylinders has continued through the years along the lines of increasing their safety and gas-carrying capacities, lowering their costs and dead-load practice, and perfecting the handling and distribution for maximum utility. More recently under his direction, a sand-lime type of filler was developed, perfected and put into production. In January 1951, the research and engineering group became the Speedway Laboratory, The Linde Air Products Co., with Mr. Ness as its manager. Mr. Ness is a member of the International Acetylene Assn., Compressed Gas Manufacturers Assn. and National Fire Protection Assn.

Oehler Promoted

Elevation of Dr. I. A. Oehler, Director of Metallurgy and Research at The American Welding & Manufacturing Co., Warren, Ohio, to new responsibilities in the company's over-all management was announced recently by E. C. Fales, Executive Vice-President.

Oehler, who will continue to direct the company's research activities, assumes the newly created post of Administrative Assistant to the Executive Vice-President.

Dr. Oehler joined The American Welding & Manufacturing Co. in 1942. Previous to that he was assistant chief metallurgist at Republic Steel Corp., Buffalo

I. A. Oehler

district. He received his E.E. degree from Rensselaer Polytechnic Institute in 1932, his M.E.E. from the same institute in 1933 and obtained his D.E.E. degree while studying on a R.P.I. fellowship.

Nationally known for his work in welding, Dr. Oehler was recently elected to the Board of Directors of the AMERICAN WELDING SOCIETY. He is also a member of the American Society for Metals, Society of Automotive Engineers, American Society for Testing Materials, American Association for Advancement of Science, National Society of Professional Engineers, American Ordnance Assn., Sigma XI and is past-chairman, Mahoning Valley Section, AMERICAN WELDING SOCIETY, and past-chairman, Warren Chapter, American Society for Metals.

Baldwin-Lima-Hamilton Corp. Promotes Kenneth G. Hubach

Kenneth G. Hubach has been appointed sales manager of the Foundry & Commercial Weldment Departments of Baldwin-Lima-Hamilton Corp. His duties will be concerned with the development of long-range possibilities in the field of metal fabrication. In heading up these sales operations, he will work toward a closely coordinated foundry and weldment service designed to meet the requirements of industry.

Hubach is a civil engineering graduate of the Newark College of Engineering. He pursued further technical studies at Case Scientific and Temple University.

In 1936, he joined the Page Steel & Wire Division, American Chain & Cable Corp., as a welding engineer. In 1942, he became general manager of the Standard Electrode & Manufacturing Co.; and in 1951, he joined the H. L. Yoh Co. He resigned from this position on Sept. 1, 1951, to join B-L-H as manager of the Commercial Weldment Division. He is a member of AWS.

Freeze Appointed Eastern Representative

The appointment of C. Louis Freeze as Representative for the Greater Philadelphia Territory has been announced by Fred A. Kaufman, General Sales Manager of The McKay Co., Pittsburgh, Pa. Mr. Freeze, from headquarters in Philadelphia, will serve as district sales representative in Delaware, Eastern Pennsylvania and Southern New Jersey for the company's Electrode Division.

Mr. Freeze brings to The McKay Co. a well-rounded background in welding. He has over 18 years of shop-level know-how in all types of welding and weldments plus experience in engineering and sales. He was associated from 1933 to 1945 with the Armco Steel Corp. in its Fabrication Division. Since 1946 he has been in electrode sales.

Mr. Freeze studied Mechanical Engineering at the American School of Chicago and attended City College in New York. He is a member of the AMERICAN WELDING SOCIETY.

Lincoln Adds New Directors

At a meeting of the shareholders of The Lincoln Electric Co., held on Apr. 4th, J. S. Roscoe and G. E. Tenney were elected as additional members of the Board of Directors. Board members for the year 1951 were re-elected for another year.

Mr. Roscoe joined Lincoln in 1924 following his graduation from the Ohio State University. He is Director of Purchasing for the company, appointed to that position in 1951. He previously was District Manager for the company in Chicago, Pittsburgh and Syracuse.

Kenneth G. Hubach

C. Louis Freeze

J. S. Roscoe

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RE-WORK WELDERS SAY
MAKES EACH JOB EASIER BECAUSE WE CAN SEE WHERE THE DEFECTS ARE!

G. E. Tenney

Mr. Tenney, Service Manager, and also a graduate of the Ohio State University, was District Manager in Chicago for 15 years before his appointment as Service Manager in 1948. He was Sales Manager for Moore Drop Forging Co. of Springfield, Mass., before joining Lincoln in 1932.

L. W. Hench New President of International Acetylene Assn.

L. W. Hench, President of American Oxygen Service Corp., Harrison, N. J., was elected President of the International Acetylene Assn. recently at the annual business meeting held during this association's Annual Convention in Indianapolis. Mr. Hench had served as Vice-President for the year 1951.

W. A. Brown, Jr., President, The Liquid Carbonic Corp., Chicago, was elected Vice-President of the Association. E. V. David was re-elected Treasurer. H. F. Reinhard was re-elected Secretary.

L. W. Hench was born in Cleveland, Ohio, and received his early education in the Cleveland Schools. Mr. Hench started his business career at the age of 16 as an electrician for Youngstown Sheet and Tube Co., Youngstown, Ohio. In succeeding years he served as sales engineer and power engineer with several mid-western industrial organizations.

Left to right: L. W. Hench, W. A. Brown, Jr., H. F. Reinhard, E. V. David

Since 1919 Mr. Hench has devoted his time to the oxyacetylene industry and to the construction of plants for the production of oxygen, acetylene and other compressed gases.

For many years Mr. Hench has taken an active part in the functioning of the Compressed Gas Assn. and the International Acetylene Assn. He served as President of the Compressed Gas Assn. in 1948.

Harnischfeger Promotions

The Harnischfeger Corp. has announced the recent personnel promotions of M. O. Monsler and W. R. Stephens.

Filling a newly created post, Mr. Monsler is now manager of Harnischfeger Corp.'s welder and electrode division after having been sales manager of this division for two years. In addition to this sales activity, Mr. Monsler brings to his managerial position extensive knowledge of welding techniques and procedures gained through 15 years of experience as a welding service engineer and superintendent's assistant in welding production and control.

Mr. Stephens is taking over the duties of sales manager of Harnischfeger Corp's welder and electrode division. Before his association with the company in 1947, Mr. Stephens obtained 11 years of experience as a research laboratory metallurgist and electrode sales engineer. He joined the Harnischfeger Corp. as a welder sales engineer in this company's Detroit office and has worked in this capacity until his recent promotion.

OBITUARY

Dr. Charles MacQuigg

Dr. Charles E. MacQuigg, Dean of Ohio State University's Engineering College for 15 years, died on April 24th after a month's illness. He was 67 years old.

Born at Ironton, Dr. MacQuigg was associated with the Sante Fe Railroad and the Anaconda Copper Co. in Montana after graduation from Ohio State. He was head of the Metallurgy Department of Pennsylvania State College for 5 years before joining the Army Ordnance Department during the First World War. Dr. MacQuigg was regional coordinator for the Government's engineering, science and management war training program during the second World War.

He was president of the American Society for Engineering Education in 1947–49; chairman of the Ohio Water Resources Board and member of the executive committee of the engineering division of the Association of Land Grant Colleges and Universities. A member of the National Research Council and the

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Newcomen Society of England, he held several patents on metallurgical inventions and was the author of numerous technical papers.

Surviving are his widow, Mrs. Lillian MacQuigg, and three sons, Major David E. MacQuigg of Fort Reilly, Kan.; Dr. Roger E. MacQuigg of Albuquerque, N. Mex., and Charles H. MacQuigg of Dallas, Tex.

C. Laurence Warwick, Long-Time Executive Secretary, ASTM, Dies

C. Laurence Warwick, Executive Secretary, American Society for Testing Materials, and its administrative head since 1919, died suddenly Wednesday evening, April 23rd, shortly after presiding at a dinner honoring the retiring Treasurer of the Society. During the meal he complained of chest pains and after taking a sedative, continued, but died, probably from a severe heart attack, about an hour after the close of the affair.

Mr. Warwick had been active in the Society since 1909 when he graduated from the University of Pennsylvania in civil engineering. While he was Instructor and Assistant Professor at the University, he also served as Assistant Secretary of ASTM with Edgar Marburg, the Society's founder secretary. In 1919, on the death of Dr. Marburg, he was appointed Secretary-Treasurer (chief executive officer) and in 1946 became Executive Secretary.

He had made many notable contributions to the field of standardization and research in materials and was recognized as an outstanding authority on materials. One of his important contributions was in the War Production Board during World War II, where he served as Head of the Specifications Branch of the Conservation Division, and later headed the Materials Division. This work resulted in tremendous savings of critical and strategic war materials through the issuance of emergency standards and in other ways.

He was born July 29, 1889. He is survived by his wife, Mary, a daughter, Mrs. Elizabeth Holtzman of Yardley, and two sons, C. Laurence, Jr., of Broomall, and Robert O., of Trenton; also two brothers, Earl of Philadelphia and Firman of New Braunfels, Tex. His mother, now 85 years old, of Philadelphia, also survives. There are 5 grandchildren.

He had written a large number of technical papers and reports dealing with properties and tests of engineering materials and especially standardization of specifications and tests. He was a member of Sigma Tau and Sigma Xi, honorary societies.

The Society, which had been the focal point of his business and technical life, is this year commemorating its 50th Anniversary during a week long meeting in New York City, June 23rd to 27th. At that time there will be greetings from various foreign delegates, many of whom Mr. Warwick personally contacted when he was in Europe late in 1951.

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NEW LITERATURE

Ampco News

The 1st quarter 1952 issue of the *Ampco Welding News* has just been released by Ampco Metal, Inc., Milwaukee, Wis.

Completely illustrated, this issue features the fabrication of aluminum bronze gear blanks using the inert-gas consumable electrode method. Other case histories give detailed information on the salvaging of seam welding and tube mill electrodes; the overlay of steel mill wobbler ends and die casting plunger tips; the welding of a cast-iron transit pump cover, etc. All articles give complete welding information concerning the techniques and processes used.

Your free copy is available by writing to Ampco Metal, Inc., 1745 S. 38th St., Milwaukee 46, Wis.

Resistance Welding Book

A new 32-page illustrated catalog of resistance welding materials has been published by Weiger Weed & Co., Detroit, Mich., division of Fansteel Metallurgical Corp.

Nearly 700 different styles and sizes of resistance welding electrodes are listed, including the new Kaptrode type electrodes, designed to conserve copper. Numerous additions have been made to the line of cold-formed offset electrodes, irregular and gun welder tips.

The catalog also lists a large number of water-cooled holders, both ejector and nonejector types, both straight and offset.

Readers may obtain copies of Catalog 14.650-3 from Weiger Weed & Co., division of Fansteel Metallurgical Corp., 11644 Cloverdale Ave., Detroit 4, Mich.

Cast-Iron Welding Alloy

A new leaflet, TI8991, featuring actual case histories covering the use of "Eutec-Trode 27," a cast-iron electrode, is available, without charge, by writing Eutectic Welding Alloys Corp., Dept. "P," 172nd St. and Northern Blvd., Flushing 58, N. Y.

Welding Rod Coating Materials

The Foote Mineral Co., 18 W. Chelten Ave., Philadelphia 44, Pa., has issued a deluxe pamphlet of 16 pages covering the welding rod coating material field completely. It covers such subjects as: the coating materials chemical specifications, alloying materials, binders and slipping agents, fluxes and slag-forming materials, arc stabilizers and other valuable information. Copies available on request.

DryRod Electrode Oven

The Philip Roden Co., 1721 E. Lake Bluff Blvd., Milwaukee 11, Wis., has just issued an attractive 6-page leaflet giving full information on its electrode oven which is designed to stop moisture pickup in mineral coated electrodes.

Welding and Riveting Larger Aluminum Structures

The Aluminium Development Assn., 33, Grosvenor Street, London, W. 1, has issued a book on the above subject consisting of 223 pages. This book includes the papers presented at a symposium on the subject together with preliminary remarks, discussion and authors' reply. There were two sessions, one dealing with welding and the other with riveting of aluminum and its alloys. Papers included argon arc welding from the research and practical viewpoint.

1951 Supplements to Book of ASTM Standards

The American Society for Testing Materials announces that the *1951 Supplements* to the 1949 Book of ASTM Standards, which is issued triennially are now available.

With the 1949 Book of ASTM Standards and the 1950 Supplements, these *1951 Supplements* give in their latest form all of the ASTM specifications, tests, definitions, etc., excepting the chemical analysis of metals.

For further information, write to American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.

Operating Data for Heliarc Torches

A convenient, pocket-sized folder containing operating data for Heliarc torches has just been released by Linde Air Products Co. Current ranges and electrode sizes for the standard tungsten and the 2% thoriated tungsten electrodes are listed in tables. A third table covers the current and number of passes required to weld various metals. Also included are suggestions for conserving tungsten electrodes, of particular importance with tungsten in such short supply.

This folder may be obtained from any Linde office or by writing direct to Linde Air Products Co., a Division of Union Carbide and Carbon Corp., 30 E. 42nd St., New York 17, N. Y.

Manganal Marketer No. 11

Manganal Special Shape Applicator Bars for the repair of tractors is the subject of the *Manganal Marketer* (Vol. 2, No. 11) available on request from the Stulz-Sickles Co., 134–142 Lafayette St., Newark, N. J.

Included in this publication is a table listing the lineal feet requirements for International, Caterpillar, Cletrac and Allis-Chalmers tractors. The repairman can estimate how much of the grouser has been worn away and pick the size bar which will bring the grouser up to original size from actual-size diagrams listed in the *Marketer*.

Complete details for welding on the bars are supplied along with explicit directions and illustrations. Also offered are other Manganal applications for repairing bulldozer blades, track rollers, drive sprockets and idler wheels.

Tempilstik° Instruction Sheet

The Tempil Corp. of New York has prepared a supplementary instruction sheet which covers the recommended use of Tempilstiks° in a variety of industrial and research applications.

The usefulness of Tempilstiks° under special environmental conditions is discussed and a number of procedures and techniques for determining temperatures in unusual applications are described.

Copies of this Tempilstik° instruction sheet may be had by writing to Tempil Corp., 11 W. 25th St., New York 10, N. Y.

Shielded-Inert-Gas-Metal-Arc Welding

Advantages of argon-oxygen mixtures in shielded-inert-gas-metal-arc welding of carbon steels are analyzed in a new booklet, *Sigma Welding of Carbon Steels*.

This 12-page study includes the effect of gas flow, current density and welding speed on porosity, and the effect of voltage on penetration when using a 5% oxygen mixture. Rod burn-off and metal deposition rates for sigma and flux-coated electrode welding are also compared.

This booklet may be obtained from any Linde office or by writing direct to Linde Air Products Co., a Division of Union Carbide and Carbon Corp., 30 E. 42nd St., New York 17, N. Y.

Booklet on Flame-Hardening

Flame-hardening of steel parts is described in a new, 8-page, illustrated booklet, *Flame-Hardening—A Flexible Method of Surface Treatment*. The booklet lists the advantages of flame-hardening, and

ARE THERE THREE GOOD WELDING ROD SALESMEN IN THE UNITED STATES?

We Need Three More Regional Representatives: 1 Eastern, 1 Mid-West, and 1 Far-West

Opportunities like these seldom present themselves in the welding industry. We are a major manufacturer of arc welding electrodes. The boss, who is distributor-minded, who isn't dazzled by defense orders, and knows our future lies in expanding and completing a nation-wide distributor sales organization, has told me to add three *good* regional salesmen—and he wants them *now.*

We *don't* want mere order-takers. We *don't* want men who'll just make routine calls on distributors. We *don't* want floaters who'll quit us because the work is too hard or because someone else offers them a couple more temporary bucks.

We *do* want: Men who have *real sales and engineering experience* in the welding electrode industry... Men who get a kick out of helping good distributors become even better... Men who can take a plan out into the field, obtain, set up, and hold new distributors.. Men who can solve technical problems on the spot.. Men who will learn our products, our policies, and follow out the only sales policy that ever succeeds: *one we all agree on, believe in, and promote...together...as a team.*

To these three men we offer: Secure executive positions with an established, growing company...Generous salaries and adequate expense accounts.. Friendly, sincere bosses and associates genuinely interested in your success...An opportunity to make more money based strictly on your individual efforts, in the field, against fair quotas...Now, if you're one of these men, *write me in strictest confidence* and tell me why I should hire you. Tell me where you headquarter, how much territory you know and can cover, who you know in the territory, what you can do for us, and how much income you need to be happy. We're sincere about this—*be sure you are.* Personal interviews will be arranged where warranted. Our own people know about this advertisement.

ADDRESS:
GENERAL SALES MANAGER
Box V-272, The Welding Journal

steels that can be hardened. Illustrations of several different types of applications show the wide variations that can be obtained from this process.

This booklet may be obtained free from any Linde office or by writing direct to Linde Air Products Co., a Division of Union Carbide and Carbon Corp., 30 E. 42nd St., New York 17, N. Y.

Rapid Determination of Copper in Iron and Steel

A rapid one-step procedure specifically designed for the determination of copper in alloy steel is described in summary Technical Report 1661 released in April by the National Bureau of Standards, U. S. Department of Commerce. This NBS method was originally reported upon in "Photometric Determination of Copper in Iron and Steel with Diethyldithiocarbanate," by John L. Hague, Eric D. Brown and Harry A. Bright, *J. Research NBS*, **45**, 380 (1951) RP 2265.

Bulletin on Atomic-Hydrogen Arc Welding Equipment

A new, two-color, two-page bulletin on single-phase, 60-cycle atomic-hydrogen arc-welding equipment has been announced as available from the General Electric Co., Schenectady 5, N. Y.

In addition to explaining the process of atomic-hydrogen welding, the new bulletin (GEC-598A) gives a description of the recently redesigned power-generating equipment and lists its specifications, applications and advantages. It also covers the features of the company's atomic-hydrogen torch.

Bulletin on Arc-Welding Accessories

A new two-color, four-page bulletin on arc-welding accessories has been announced as available from the General Electric Co., Schenectady 5, N. Y. The illustrated bulletin (GEC-864) covers more than a dozen holders, ground clamps and connectors, and describes the uses, operation and specifications of each. For a copy of this bulletin write to the General Electric Co. at the above address.

Welding of Kirksite Die Castings

A new leaflet, featuring a reprint of an article entitled "Zinc Die Cast Can Be Welded" showing how Kirksite dies and other zinc die castings can be welded without melting the parent metal, is available from Eutectic Welding Alloys Corp., Flushing, N. Y.

The article contains case histories, photographs, data and technical information on the reclamation and repair of a massive Kirksite die as well as a delicate white metal scale balance arm.

Copies of this new leaflet, *TIS 969*, may be obtained without charge by writing Eutectic Welding Alloys Corp., Dept. "P," 172nd St. and Northern Blvd., Flushing 58, N. Y.

Welding Aluminum Bronze

Available is a 12-page reprint of a talk, "Welding Iron-Bearing Alpha Aluminum Bronze," presented by F. E. Garriott, Manager of the Weldrod and Wire Department, Ampco Metal, Inc., Milwaukee, Wis., at the annual meeting of the AMERICAN WELDING SOCIETY.

Profusely illustrated this booklet discusses test results of the weldability characteristics of aluminum bronze sheet and plate. Charts, graphs and photographs help describe welding techniques and processes such as carbon-arc, inert-gas metal-arc, metal-arc, inert-gas consumable electrode and submerged arc.

Fabrications of aluminum bronzes and the welding processes used are also described.

A free copy may be obtained by writing Ampco Metal, Inc., 1745 S. 38th St., Milwaukee 46, Wis.

Brazing Manual

A "Brazing Manual," 16 pp., 6 x 9 in., illustrated, has just been published by All-State Welding Alloys Co., Inc., White Plains, N. Y. The publication is designed particularly for the service trades. Containing data for brazing shapes, sheet, castings, tubing and assemblies of copper, brass, steel, aluminum and cast iron, it will be helpful to all who have such work to do.

Copies of the new manual are available without obligation, from All-State Welding Alloys Co., Inc., White Plains, N. Y., and from All-State distributors throughout the country.

Cost-Cutting

A new booklet outlining cost-cutting solutions to common problems in metallic arc, inert arc and other fusion welding of alloy steels, and describing the available types of Solar Flux, is available from the Flux Department, Solar Aircraft Co., 2200 Pacific Highway, San Diego 12, Calif.

The booklet illustrates the sources of common difficulties in the welding of alloys. It also describes how Solar Back-Up Flux reduces welding time as it removes dirt and oxides, aids even penetration, prevents burn-through, protects the back side of the seam and supports the molten weld metal.

Solar, one of the nation's leading fabricators of alloy steels for jet engine components and other uses, developed four types of Solar Back-Up Fluxes to solve problems in the company's own manufacturing operations. These back-up materials are now available to other firms engaged in alloy steel welding.

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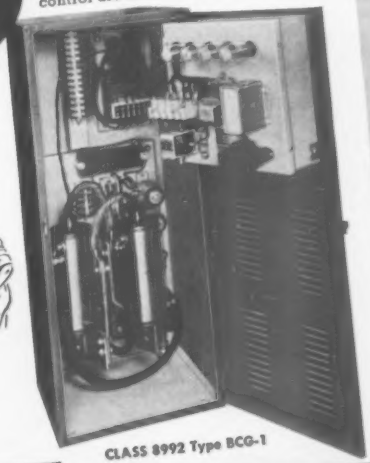

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NEW PRODUCTS

New Lightweight Electrode Holder

A new, lightweight, 300-amp. electrode holder has just been introduced by the Tweco Products Co., known as the Model A-732 Twecotong Holder. It features a lightweight, high-copper alloy for maximum conductivity. Raised upper lever allows plenty of room for the operator's hand with a welding rod in the jaws. Body and tip ends of the holder are insulated with Tweco's Patented "Super-Mel" Insulators. Tip-end insulators are interchangeable.

The New A-732 Twecotong Electrode Holder will handle from $^1/_{32}$- through $^1/_8$-in. electrodes. The welding cable may be soldered or clamped mechanically to the body of the holder. Only $9^1/_4$ in. in length, the new holder makes it easy for the operator to weld in those "hard to get at" places. The holder is especially designed for high-speed production, pipe welding and job shop work.

Complete information, prices and specifications on this new holder and a complete line of arc-welding cable accessories, is given in the No. 8 *Twecolog* which is available without charge from the Tweco Products Co., P. O. Box 666, Wichita, Kan.

AC Welders

Metal & Thermit Corp., New York, announces a complete new line of AC welders. According to this company, the new welders incorporate three highly important features contributing to longer welder life, improved performance, and a high degree of operator acceptance.

First of these features is insulation with silicone. Use of this new semiorganic insulating material supposedly provides greater overload capabilities, permits more compact, lighter weight design and prolongs welder life.

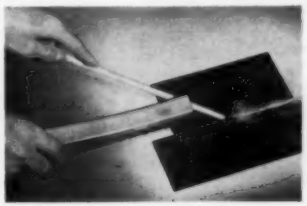
Second feature is the combination of low open circuit voltage with arc stabilization, accomplished by incorporating capacitors in the secondary circuit to provide an extra surge of current if the arc starts to go out. It is reported that this results in smoother performance and elimination of "pop-outs."

Third feature is automatic hot-start which is intended to make arc striking easy by providing just the right amount of current boost to start the arc at any current setting without manual adjustment. The hot-start device is a simple relay and resistor combination connected across the transformer secondary in series and is fully automatic in operation. Controls of the mercury relay are sealed in and no maintenance is required at any time.

Complete information on the new welder line, made in 200-, 300-, 400- and 500-amp. ratings, is contained in a series of catalog sheets, each sheet for a different size of welder, which are available on request from Metal & Thermit Corp., 100 E. 42nd St., New York 17, N. Y.

Galvanized Coating Material

The Metalloy Products Co., distributors of Galvalloy, announce they have reduced the bar length from 16 to 14 in. in length, thereby making the bar easier to use, as well as reducing the possibility of breakage.



Galvalloy is intended to bond to any metal without the use of flux. It is rubbed on the preheated surface and supposedly will bond to such an extent that it cannot be burned off, even though the base metal is heated to a cherry red.

For further particulars, please write: Metalloy Products Co., 1351 E. 17th St., Los Angeles 21, Calif.

Aluminum and Stainless Steel Fluxes

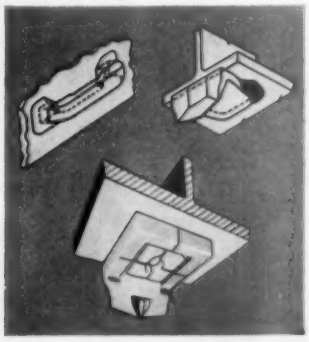
The All-State Welding Alloys Co., White Plains, N. Y., have announced a new welding flux which is equally effective as a paste or a powder. It is suitable for welding aluminum alloys and also for the gas welding of stainless steels. In this latter it is claimed that it does not break down temperatures required for the welding of stainless steel. It is designated as All-State No. 35 Aluminum Welding and Stainless Steel Flux.

Adjustable Welding Connector

J. H. Williams & Co., manufacturers and sole distributors of Saxe Erection Units used in assembling structural steel for welding, announces the development of a new adjustable clip known as K3A.

This new clip offers a $^1/_4$ in. adjustment which greatly facilitates the erection of welded-steel, multiple-story building construction. Column variations from a true straight condition, caused by tolerances which are permitted in mill-rolled columns, make the announcement of this adjustment feature welcome news to erectors of structural steel secured by welding.

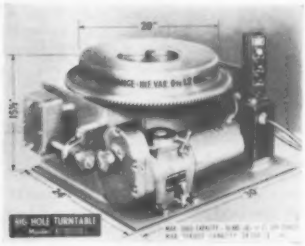
The new adjustable K3A clip provides easy adjustment in structural steel as-



sembly for the first time and it supplements the standard K3 connection long in use in the popular Saxe Welded Erection System. This System saves steel, produces fabrication economies and speeds erection. Write to J. H. Williams & Co., 400 Vulcan St., Buffalo 7, N. Y., and ask for Bulletin No. 5.

Big Hole Turntable

The Aronson Machine Co. announces the availability of their Model X-20115 Big Hole Turntable designed for the purpose of mounting on a bench, the floor or a pit to rotate heavy, large diameters on the horizontal plane only for welding, painting, cleaning, etc.



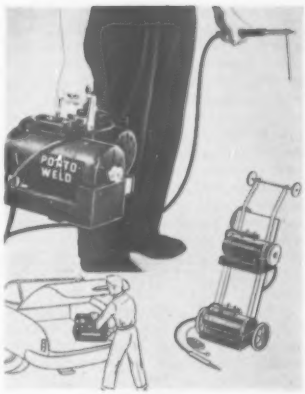
With the 9-in. hole in the center of the turntable, spindle shafts can be positioned without special fixturing, according to the manufacturer. A minimum space is taken up by its compactness. Infinitely variable speeds of the worktable from zero to 1.2 rpm. handle a wide range of work. A remote push-button control and magnetic reversing starter are standard equipment.

Heavy-Duty Welding and Brazing Unit

Called Porto-Weld, a new line of all-in-one heavy-duty welding and brazing units is announced by Generator Sales Co., 1627 N. Damen Ave., Chicago 47, Ill., which also have built-in power equipment for grinding, buffing, polishing, sanding, brushing or sawing. This unit, according to its manufacturers, is extremely versatile, easily portable, and economical to use.

Porto-Weld Model 2-A (see accompanying illustration) is in the form of two parallel slightly staggered cylinders 12 in. long and 6 in. in diameter, mounted on a base approximately 13½ x 15 in., with a large metal carrying handle rising in the center.

The equipment includes: (*a*) Motor generator (manufactured by General Electric Co. in accordance with the U. S. Air Corps specifications) with life sealed ball bearings. No oil is necessary. The rotor is precision balanced to eliminate vibrations. (*b*) Standard accessories such as buffing wheel, wire brush wheel, grinding disk, electrode holder, welding cable, ground cable, single-groove "V" pulley 1½ in. in diameter, sample electrodes and a welding shield.



Porto-Weld 2-A operates on 110-v., 60-cycle a. c. or d. c. Speeds range from 2000 rpm to 10,000; amperage rating 0–150 amp. It has 8 welding ranges.

For additional information write directly to General Sales Co. at the above address.

Heating Torch

Industrial Engineered Products Co. of Los Angeles introduces its new heavy-duty lightweight Bazooka Torch.... It is extremely hot, yet comfortably cool.

The self-cooled adjustable pistol grip handle may be easily moved close to the burner for better control or back away from the reflected heat of the work. Excellent for reaching heavy-duty jobs in "hard to get at" locations where a heavy concentration of heat is desired. Weighing only 2½ lb., complete with hose assembly, this unit produces a flame range

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NEW LITERATURE

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Sight Feed

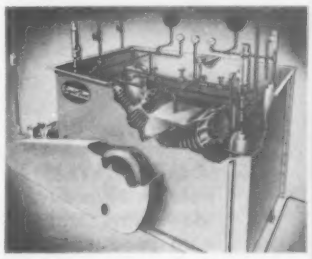
COMPLETE ACETYLENE COMPRESSING PLANTS

Featuring The

MODEL A-TWIN GENERATOR

and

MODEL M-1 COMPRESSOR



If you are planning an acetylene compressing plant installation, or enlarging present production facilities, write for catalog CP-152. This new literature fully describes Sight Feed's Acetylene Compressing Plant Equipment.

You'll read why the Model A-Twin Generator and M-1 Compressor are capable of producing larger quantities of acetylene in your plant at lower cost—and without the need for gas holders.

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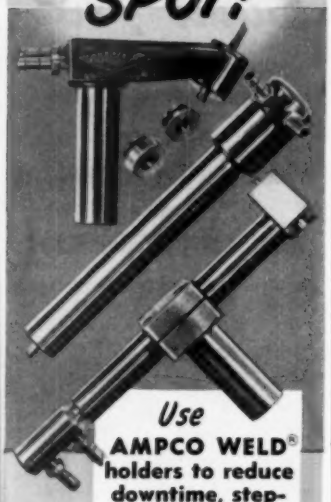

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There's an AMPCO WELD® holder for every resistance-welding job — offset ejector holders, straight ejector holders, universal ejector holders. All are leak-proof. Made of high-conductivity Ampco Bronze alloys, they meet or exceed RWMA specifications to give you trouble-free operation, longer runs, reduced downtime, and increased output.

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from a soft, lapping flame of 5 in. long and 1 in. in diameter to a large hard-blast flame of 20 in. long and 5 in. in diameter.

The Bazooka was designed especially for the industrial field and is operated from standard liquid petroleum gas (butane-propane) cylinders at tank pressure with no gas regulator required. Excellent for preheating and annealing operations, rebabbitting bearings, large electrical cable soldering, solder wiping, large diameter copper sweat fitting installations, heavy steel metal soldering, melting out leaded soil pipe joints and numerous other operations where the use of a lightweight and flexible, but heavy-duty torch is required.

A new catalog showing the complete Torchmaster line is now available, without cost or obligation, by writing directly to Industrial Engineered Products Co., 7416 Melrose Ave., Los Angeles 46, Calif.

Portable Surface-Resistance Indicator

A portable surface-resistance indicator, designed to provide a rapid and accurate measurement of the resistance between pieces of metal to be welded, has been announced by the Special Products Division of the General Electric Co.

The new device, developed by the company's General Engineering Laboratory, is intended to supply a simple check on pre-welding cleaning processes, upon which the surface resistance of the metal depends. Small changes in concentration or slight contamination of cleaning solutions cause surfaces resistance to vary widely, G-E engineers said, and ultimately result in an unsatisfactory resistance welding bond.

In resistance welding aluminum, for example, electrode pickup, inconsistency of welds and metal expulsion can be greatly reduced by knowing the surface resistance of the metal before welding, the engineers said.

The new equipment comprises two parts—a microhmmeter and a sample holder. The sample holder consists of an hydraulic ram which has a pair of current electrodes, emf. electrodes and a pressure gage. The emf. electrodes are so spaced as to make the measurement independent of sample size.

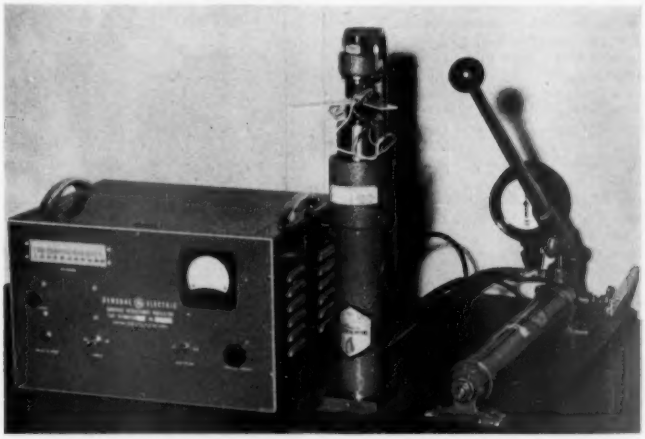
In operation, the sample pieces of metal to be welded are placed between the jaws of the sample holder and subjected to the desired pressure. The surface resistance between the metal samples is indicated on the microhmmeter, which is connected electrically through an extension cable to the sample holder. The entire operation supposedly can be completed in a matter of seconds.

The unit has two ranges: 0–200 and 0–2000 microhms. The measured resistance is indicated directly in microhms on a linear 100-division scale. Voltage fluctuations in the supply mains do not affect the reading.

The microhmmeter is 9½ x 15 x 11 in. and weighs 23 lb. The sample holder weighs 30 lb., has a clamp throat depth of 3 in., electrode clearance of 2 in., electrode surface radius of 4 in. and electrode diameter of ⅝ in.

Repair of Oxyacetylene Hoses

Gas Arc Supply, 223 N. 16th St., Philadelphia 2, Pa., has introduced a new "Fast Fix" kit for on-the-job repair of cutting and welding hose. Believed to be the first such kit ever offered, the "Fast Fix" is complete with all necessary tools



and replacement parts for (1) putting a new nipple-ferrule-nut assembly on the end of a length of hose, (2) permanently splicing two lengths of hose, (3) temporarily coupling two sections of hose. There is nothing makeshift about these operations (no clamps, etc.), the finished work being equal to that found on the original equipment. The great advantage, of course, is that hose repairs can be made immediately, on the job, without the delay and cost involved in taking hoses back to a dealer for repairs or for splicing.

For a catalog sheet or further information on the "Fast Fix" Hose Repair Kit, write Gas Arc Supply, 223 N. 16th St., Philadelphia 2, Pa.

Women Welders' Protective Clothing

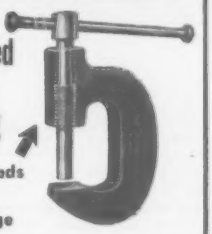
Welders' protective clothing, designed exclusively for industry's feminine workers, is announced by American Optical Company, Southbridge, Mass.

This clothing, according to the manufacturer, is styled to allow free and easy movement of the body; yet, it fits so snugly that there are no gaps or openings to permit entrance of flying sparks. Also, clothing is light in weight.

The new protective clothing is made of specially selected chrome tanned leather, simulating a soft, suedelike appearance.

Additional information may be had by writing to the American Optical Co., at the above address.

"Red Head"
WELDING CLAMPS



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• No Threads To Damage

1. Case Hardened threads are always protected from weld spatter and never exposed to damage in open or closed position.

2. The clamp body is cut from solid plate, thereby insuring extreme rigidity and giving great resistance to bending or twisting.

3. Heat treated chrome molybdenum alloy handle offers great resistance to bending.

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Graduate Engineer with two to four years' experience in resistance and fusion welding to assist in aircraft design applications, processing problems and development work. Should be acquainted with types of welding equipment used on ferrous and non-ferrous metals and able to correlate design and metallurgical requirements with processing methods.

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...Reduced arc blow
...Completely adjustable by operator

Westinghouse RA Welders with new positive arc-drive control now prevent shorting when used on "drag" welding applications. In addition, they allow complete penetration on root passes of vertical and overhead welds. Arc-drive control is obtained by adjusting the ratio of short-circuit current to welding current without changing open-circuit voltage. Actual amount of arc-drive current can be varied by the operator.

For information on this improved RA Welder or other Westinghouse Welding Equipment, write Westinghouse Electric Corporation, Dept. DC 85, Welding Division, Buffalo, New York. J-21607-A-1

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WELDING EQUIPMENT

abstracts of
CURRENT WELDING PATENTS

prepared by V. L. Oldham

Printed copies of patents may be obtained for 25¢ from the Commissioner of Patents, Washington 25, D. C.

2,590,084—Shielded - Arc Welding Method and Gas Confining Means—Arthur A. Bernard, Chicago, Ill., assignor to National Cylinder Gas Co., a corporation of Delaware.

By this method, a space around the arc is enclosed to confine the arc-generated gas and a gaseous fluid lighter than the arc-generated gas is continually introduced into this confined space above the lower end of the arc. This enclosed space is vented at a level above the lower end of the arc, and the introduction of the gaseous fluid and the venting is correlated to cause the arc generating gas and the gaseous fluid to form separate bodies at substantially the venting level. The venting level is varied to shift the interface between the fluid and the gas to vary the rate of metal deposition by the electrode.

2,590,577—Welding Cabinet—Richard Ruemelin, Milwaukee, Wis.

The patented welding cabinet has a top wall, a rear wall and an open front with a baffle extending forwardly and upwardly of the cabinet from the rear wall. An elongated opening is formed above the baffle to connect the rear portion of the cabinet to the front portion. The enclosure has an exhaust vent communicating with the rear portion of the cabinet and an exhaust blower has an inlet that communicates with the exhaust vent.

2,590,582—Welding Control—Clarence B. Stadum, Buffalo, and William E. Large, Tonawanda, N. Y., assignors to Westinghouse Electric Corp., East Pittsburgh, Pa., a corporation of Pennsylvania.

This welding control relates to a system for reducing spitting during spot welding of oxide coated metal. The system includes the provision of means for passing a relatively low preheating current through the metal, means for applying greater than the predetermined forge pressure to the metal during flow of the preheating current, and means are provided for increasing the preheating current to a predetermined welding value and for reducing the forge pressure to a predetermined forge pressure during a spot weld period following the flow of the preheating current.

2,591,302—Seam Welded Blanks and Methods of Making Them—Karl L. Schiff, Philadelphia, Pa., assignor to The Budd Co., Philadelphia, Pa., a corporation of Pennsylvania.

This method is for seam welding adjoining margins of two sheets together. It includes the step of arranging the margins at a small angle to the normal direction of movement of the sheets through a roller-welding machine, the normal direction of sheet movement being at right angles to the axes of the welding rollers. The method comprises the step of guiding the sheets in the normal direction between the rollers which are of a width at least equal to the projection of the margins of the sheets on the axes of rotation of the rollers.

2,591,582—Welding Transformer—Gib Monette, Chicago, Ill., assignor to Atomiko, Inc., Chicago, Ill., a corporation of Illinois.

Monette's transformer includes a closed primary magnetic core with a plurality of legs being joined by a plurality of yokes, and a primary winding encircles a leg of the core. A secondary winding is telescoped over the primary winding and has one side of its inner wall spaced a substantial distance from the outer wall of the primary winding. A secondary magnetic core extends from the yokes of the primary core and passes axially through the space between the walls of the primary and secondary windings to be inductively interlinked with the secondary winding only. A tertiary winding is connected in series with the secondary winding and rectifying means are in circuit with the tertiary winding.

2,591,809—Apparatus for Welding Seams in Cylindrical Vessels—Roy E. Hanson, Altadena, Calif.

Hanson's apparatus has an electrode carriage arranged for linear movement parallel to the seam to be welded and it pivotally suspends a welding head therefrom. Additional means are provided to impart reciprocating motion to the welding head in a plane transverse to the seam. These last-named means are of special construction.

2,591,926—Inert - Gas - Shielded - Arc Welding Method—Glenn J. Gibson, Chatham, and Gilbert R. Rothschild, Somerville, N. J., assignors to Air Reduction Co., Inc., a corporation of New York.

This patent relates to arc welding wherein the arc is blanketed with a homogeneous mixture of helium and argon in which 20 to 60% of the mixture by volume is helium and the balance is argon.

2,591,972—Electric Welding Supply Circuit—Charles E. Slade, Wembley, and Arthur Kershaw, London, England, assignors to The Hartford National Bank & Trust Co., Hartford, Conn., as trustee.

This patent relates to an electric welding system for producing a welding voltage and it has special capacitive elements connected to a welding transformer. Several switches are in the apparatus and controlled by various means in the circuit to control the welding voltage.

2,591,994—Process of Brazing Thin Brass Members—Horace W. Alexander, Oakwood, Ohio, assignor to General Motors Corp., Dayton, Ohio, a corporation of Delaware.

Alexander's patented brazing process includes placing a thin brass brazing sheet material between the portions of the brass members to be joined and folding an edge portion of one of the brass members over an edge of the second brass member to clamp such members together with the brazing sheet material in between and leaving a slight crevice between the folded over portion and the adjacent portion of the second member. A special paste is applied and is heated in a nonoxidizing atmosphere to fuse together the adjacent portions of the brass members while excessive distillation of zinc from the brazing material is prevented.

2,592,505—Welding Tool—John S. Wolfe, Milwaukee, Wis.

This welding tool includes a wall member forming a hollow elongated nozzle with an outwardly flaring intake opening in the side of the nozzle adjacent an end thereof. Air exhaust means connect to the opposite end of the nozzle for inducing air to enter this opening and flow therethrough.

2,592,648—Combination Weld Cleaning and Chipping Tool—John W. Bowers, Wallingford, Pa., assignor to The Fibre-Metal Products Co., Chester, Pa., a corporation of Pennsylvania.

The combination tool of this patent includes a handle with special brackets thereon for carrying a wire brush thereon. A chisel member is provided in an integral continuation of a bead portion on an extension of the handle.

2,593,374—Drop Forged and Welded Brake Head—Loren L. Whitney, Hammond, Ind., assignor to American Steel Foundries, Chicago, Ill., a corporation of New Jersey.

This patent is on a special brake head wherein a weld is used to connect transverse webs in a brake structure.

SECTION NEWS AND EVENTS

as relayed to C. M. O'Leary

Applied Welding Engineering

Baltimore, Md.—The technical session of the April 21st meeting of the *Maryland* Section was preceded by showing of a film "Pipeline to the Sky" through the courtesy of the General Electric Co. This excellent film illustrated the part that nature plays in the development of our vital water supply and need for conservation and care on our parts to maintain the supply at an adequate level.

The technical speaker was Roger W. Clark, AWS, Steam Turbine Division, General Electric Co. Mr. Clark gave an excellent talk on "Welding Fabrication for High Temperature Application." As the first part of his talk Mr. Clark showed the AWS Strip film "Applied Welding Engineering" to illustrate that the problem today is not necessarily to sell welding but to sell the proper application of it. In the second part of the talk, Mr. Clark further carried out the theme of the film by presenting an application on steam turbines which illustrated that even on one application many different service requirements may be encountered. Responsibility for any joining process lies with the engineer. He must be aware of the service conditions to be encountered and make sure that the weld as designed and produced will do the job. In the design of a turbine there are a changing set of conditions of temperature and pressure in different sections of the turbine requiring different materials and fabrication procedures to suit the requirements peculiar to the individual sections. Quality control is another very important factor used as a frequent check on the end product. It has been found that appearance and soundness of a weld are closely allied and provide a constant check for use throughout the welding process. One excellent method for attaining quality in the welds is to provide for comparison a specimen made up of typical welds of good quality similar to joint designs to be encountered in the finished product. If you can establish before production what the requirements are from an engineering standpoint and combine design with quality control, you can fabricate a better product. Also to be kept in mind is the fact that the proper application of welding must include consideration of all three phases of the production cycle: design, manufacture and quality control.

Why Did It Fail?

Bethlehem, Pa.—Approximately twenty six members and guests attended the *Lehigh Valley* Section dinner held at the Hotel Bethlehem, Bethlehem, Pa., on April 7th. J. E. McCracken, Sales Engineer, Highway Specialties, Bethlehem Steel Co., gave a short introductory talk in connection with the colored moving picture entitled "The Open Road" produced by the Bethlehem Steel Co. This very interesting picture showed the many uses of steels in modern highway construction.

Sixty-four members and guests were present for the technical meeting which followed. M. V. Herasimchuk, Maintenance Metallurgist for the Bethlehem Plant of the Bethlehem Steel Co. gave an instructive talk on analyzing and correcting chronic equipment failures. If the measurements of location of failure are constant, check the design. If the measurements of location of failure are not constant, check the metallurgical history. He also stated that engineers must recognize that alternating loads reduce the materials tensile strength. Slides were used to effectively illustrate the points made in his talk.

Mr. Herasimchuk graduated from Massachusetts Institute of Technology with a B.S. degree in Metallurgical Engineering in 1939. He started working for the Bethlehem Steel Co. in the same year and has worked in the Forging Department, Heat Treating Department and Metallurgical Laboratory. At present he is Maintenance Metallurgist for the Bethlehem plant.

Structural Welding

Birmingham, Ala.—La Motte Grover, AWS, Structural Welding Engineer, Air Reduction Sales Co., was the principal speaker at the final meeting of the *Birmingham* Section for the 1951–52 season. The meeting was held April 9th and was preceded by a dinner at Hooper's Cafe.

"Practical Aspects of the Design and Fabrication of Welding Steel Construction" was the topic Mr. Grover selected to discuss.

In his address Mr. Grover emphasized the many advantages resulting from the adoption of welded construction by designing engineers, architects and owners for their structures. He also told of the unusual progress made in welded structural work in areas where designing engineers, architects and fabricators with the necessary know-how team up. Birmingham was mentioned as one such area where several architects and engineers have joined with The Ingalls Iron Works Co., a pioneer in welded structural work, to utilize welding's advantages.

Quoting K. H. Gayle, Jr., Ingalls' President, Mr. Grover, added "Ingalls is one of the few major fabricators which offers a definite cost saving through the use of welding in lieu of riveting. There may be cases where the use of welding will not afford such saving, but we have failed to find such a case. This statement is a carefully considered one made on the basis of experience obtained from dozens of switch-overs from riveted to welded construction."

Mr. Grover has been associated with Air Reduction Co. during the past 12 years, assisting designers, fabricators, railroads and shipbuilders in the development of design practices and fabricating procedures for welding. He is author of *Manual of Design for Arc Welding Structures* as well as many technical papers on welding methods and procedures. He is Chairman and member of many committees of the AMERICAN WELDING SOCIETY and the Welding Research Council, a member of the American Society of Civil Engineers and the American Society for Metals, and is a registered professional engineer.

The Birmingham Section is sponsoring the formation of two new Sections or Section Divisions of the SOCIETY in the North Alabama area and two organizational meetings have been held at Decatur, Ala. Approximately 175 engineers and executives in the area were invited to the first meeting on March 14th, and 35 persons other than the organizing group attended. John B. Wood, Public Relations Director for the Decatur Iron and Steel Co., told the "Disco Story" that adroitly coupled the company's history with welding. Joe Magrath, National Secretary of the SOCIETY, attended this first meeting as did District Vice-President J. U. Durham. The meeting served as an excellent indication of interest in SOCIETY activity in the area and it was decided to work toward two Sections or Section Divisions, depending on the number of members signed up.

One Section will be located at the Tri-City area of Florence, Sheffield and Tuscumbia, Ala., and dues have already been collected for 43 new members. As the minimum number of 50 members required for a new Section will certainly be exceeded, plans have been made to present the dues collected for the new members and a petition for a Section Charter to a representative of the SOCIETY at a dinner meeting to be held April 25th, at the Muscle Shoals Hotel in Sheffield.

Another Section or Section Division will be built around new memberships in the Decatur-Huntsville area. Decatur and Huntsville are both industrial communities located 35 miles apart. A second meeting was held at the Decatur Trade School on April 11th, with 35 persons from only the Decatur-Huntsville area attending. La Motte Grover presented the same talk previously given before the Birmingham Section in order to show prospective members just what they could expect in the way of Section activities. Mr. Grover's

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talk was well received and he was held long after adjournment time by questions from the floor.

During the business session of this second meeting at Decatur it was decided that a stronger Section could be built by Decatur, Huntsville and other nearby communities joining together in one large Section. Therefore, another meeting was scheduled for May 9th, at which time it is expected enough new members will be signed up to petition for a Section Charter. It was also decided that if the area was somewhat short of the required 50 members for a new Section, then a Section Division of the Birmingham Section would be established until the required number of members was obtained.

Annual Meeting

Boston, Mass.—The Annual Meeting of the *Boston* Section was held on April 14th in the Graduate House, M.I.T., Cambridge, Mass. After the usual cocktail and social hour the members and guests enjoyed a good dinner at which the SOCIETY was honored by the visitation of Phil Rugg its former Secretary and Treasurer for many years. Mr. Rugg is now President of The Engineering Societies of New England.

A certificate of appreciation for his work and interest in the Section was presented to Herbert Austin by Mr. Miller of the Committee of Awards. This certificate indicated the years of service devoted to the Chapter including the Chairmanship for the years 1946–48. Mr. Austin responded with one of his usually fine talks. The speaker of the evening, Clement A. O'Bryan, Special Agent of the Federal Bureau of Investigation, gave an interesting account of the growth of the F.B.I. from its start by Theodore Roosevelt in 1908 to the present time and mentioned some of the interesting criminal cases that were solved in the Boston District. This was followed by a technical movie "The Making and Shipping of Steel," through the courtesy of the United States Steel Co.

The following officers were declared for election for the year 1952–53: P. Edward McKenna, U. S. Steel Supply Co., Boston; Francis L. Brandt, Jr., Thomson Electric Welder Co., Lynn; Louis I. Dexter, Rumford Steel Products, Inc., Providence, R. I.; Hermon L. Toof, Providence Steel & Iron Co., Providence, R. I.; Edward V. Konetchy, Walworth Co., South Boston; Albert O. Wilson, Jr., A. O. Wilson Structural Co., Cambridge; and H. Hugo Stahl, Stahl Equipment Co., Brookline.

Shipyard Visit and Shipbuilding Session

Boston, Mass.—An unusually interesting meeting of the *Boston* Section was held on March 27th in conjunction with a visit to the immense Quincy Shipyard of the Bethlehem Steel Co. The meeting was arranged as a joint meeting of the Boston Section of the AWS and the Boston Chapter of the ASME.

Approximately 180 members of both organizations almost equally devoted among membership of the two societies joined in a dinner at the Administration Building Restaurant. H. K. Barton of the Shipbuilding Division of the Bethlehem Steel Co. welcomed the two Societies to the Shipyard and introduced the speaker of the evening, Capt. F. H. Whitaker, U.S. Supervisor of Shipbuilding, who talked on "Some Aspects of the Navy Shipbuilding Program." This interesting paper was followed by a motion picture "This Is Your Navy."

Welding in Heavy Industry

Buffalo, N. Y.—The *Niagara Frontier* Section held its regular monthly dinner meeting on April 24th at the Sheraton Hotel in Buffalo. Forty-eight members and guests were present at dinner while 57 attended the technical meeting which followed. H. (Jerry) Ralston, United States Steel Corp., read an excellent paper on "Welding Applications in Heavy Industry." Mr. Ralston's nontechnical paper was of general interest to all.

This was the last meeting of the season. The annual spring dance is scheduled for June 6th when the duly elected officers will be installed.

Annual Structural Meeting

Cleveland, Ohio—Dr. Harry C. Boardman, AWS, Chicago Bridge and Iron Co., was the technical speaker at the annual structural meeting of the *Cleveland* Section held on April 9th at the Hotel Allerton. Eighty-five members and guests were present to hear Dr. Boardman talk on "Welding in the Future."

At the predinner get-together guests were introduced, among whom were Myron Stepath, Puget Sound Section Past-Chairman, and Fred Tate, Pittsburgh Section Past-Chairman.

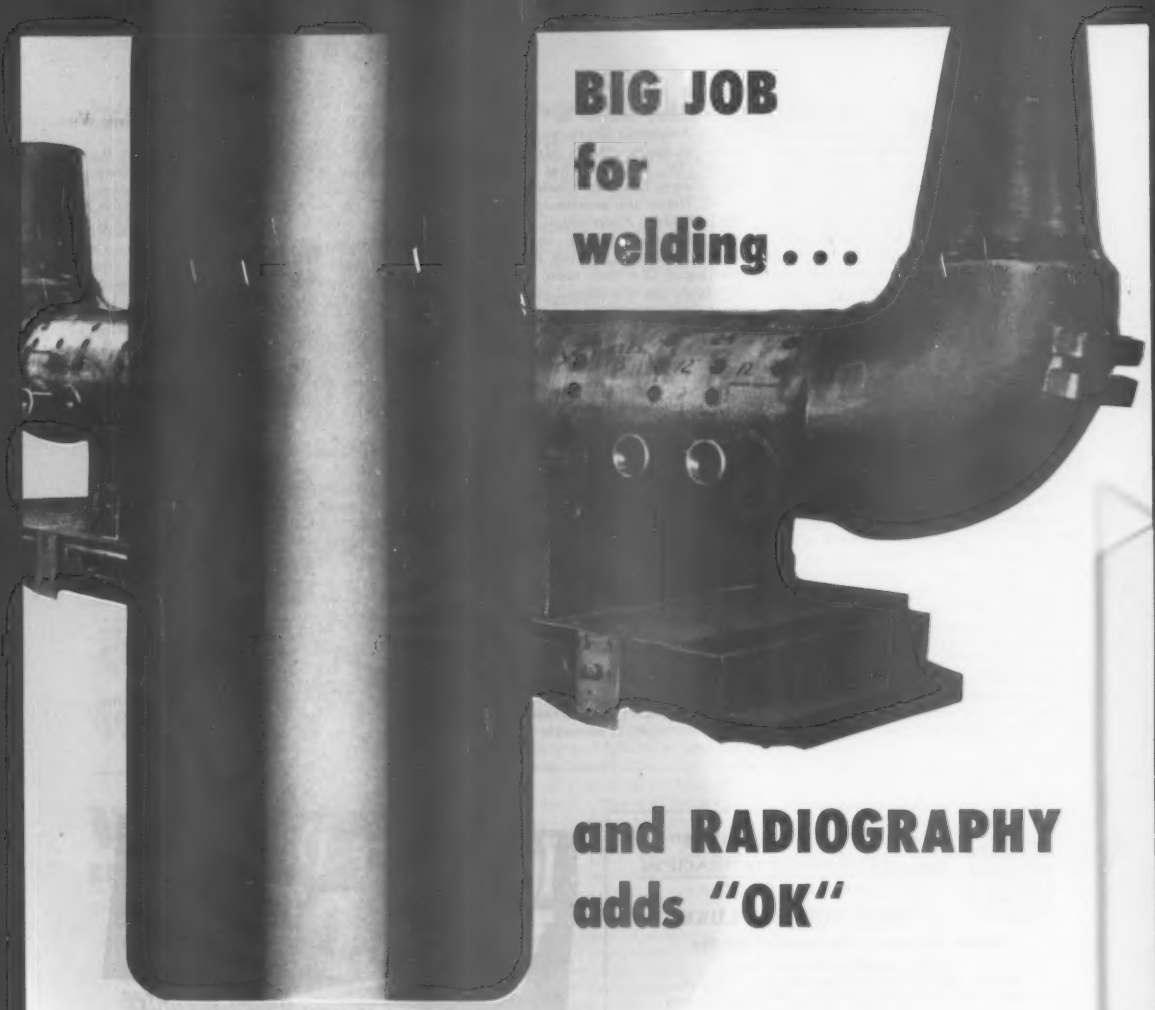
The meeting was opened by Chairman John Austin who reported that a plant visit to the Euclid Road Machinery Co. was enjoyed by 75 members who had their eyes opened by some of the production welding done on Euclid's 50-cu. yd. trucks.

The National Director, Mike Shane, former section Chairman, spoke briefly on behalf of the section membership in recognizing the services of Past-Chairman Cal Wyss. A pin was presented to Mr. Wyss.

A brief talk by Donald Sargent on "Investment Stock Buying" preceded the technical session. Mr. Sargent is a member of the firm of Saunders, Stivers and Co. After discussing various phases of investment buying, Mr. Sargent gave his opinion that we are in for a period of further inflation and that common stocks are a good hedge against this.

The coffee talks have been arranged for the section this year by Ross Yarrow, AWS.

Dr. Boardman opened his remarks with a brief discussion of the difference in behavior of carbon steel in riveted structures and welded structures. He indicated one reason some structural people worry about welding is because carbon steels do not behave the same at low temperatures as they do at ambient temperatures, especially in



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the presence of notch effect. His remarks led to the conclusion that the quality of steel used is one major importance and urged an effort to encourage mills to produce tougher carbon steels. He cited a test made at various temperatures on girders made of killed and semikilled steel. The killed steel girders all deflected considerably more than the semikilled girders and those tested at ambient temperatures deflected 16 in. and still had not failed. Dr. Boardman urged the development of tests by mills to determine if steels being made are tough at low temperatures, especially in the presence of notch effect.

Dr. Boardman then reported some of the activities of the Welding Research Council of which he is chairman. A new steel is being tested at Rensselaer Polytechnic Institute which can be used up to 50,000 psi. Tests are also being made to determine how effective are various methods of stress relieving. M.I.T. is testing to determine the spacing of stitch welding under various conditions. Columbia is testing wide flange beams for shock loading.

His closing remarks encouraged designers and engineers to use their imagination in applying welding, using different and new shapes, using a variety of different materials, all made possible by the welding process. He warned not to be tied down by hide-bound convention in our thinking about welding in the future.

Dr. Boardman is Director of Research for Chicago Bridge and Iron Works. He is an Honorary member and past-president of the AMERICAN WELDING SOCIETY. He received the SOCIETY'S Miller Medal in 1942. Dr. Boardman was introduced by Bob Henry, Technical Chairman.

Mr. Henry also announced the 13th Annual Welding Symposium, sponsored by the Cleveland Section, to be held on Friday, May 9th, at the Hotel Allerton starting at 12 o'clock noon. He said that the space for educational exhibits had already been oversubscribed and that a good exhibit was assured. The technical speakers for the afternoon: R. C. Glatz, AWS, Perfection Stove Co.; Nick Jessen, AWS, Babcock and Wilcox; and La Motte Grover, AWS, Air Reduction Sales Co. Dinner speaker: Dr. Ralph L. Lee, AWS, of the General Motors Corp.

Weldments

Denver, Col.—G. E. Linnert, AWS, Armco Steel Corp. was the guest speaker at the April 15th dinner meeting of the *Colorado* Section held at the Shirley Savoy Hotel, Denver. As an afterdinner feature, 67 members and guests were treated to an unusual talk on "How the Federal Reserve Bank Functions" given by W. Duck of the Federal Reserve Bank of Kansas City. Mr. Linnert's extemporaneous talk on "Stainless Steel Weldments" was excellent in quality and technical in nature. Slides were used to illustrate the talk.

Conference on Electric Welding

Detroit, Mich.—A detailed report by B. E. Rossi, AWS, on the Third Conference on Electric Welding held in cooperation with the *Detroit* Section and the Detroit Industrial Electrical Engineers' Society is given elsewhere in this JOURNAL.

Weld Cracking

Erie, Pa.—"Weld Cracking and Porosity" was the subject of a talk given by Julius Heuschkel, AWS, Manager, Welding Section, Research Laboratory, Westinghouse Electric Corp., at the April 22nd meeting of the *Northwestern Pennsylvania* Section held in Siebenbuerger Hall in Erie, Pa.

Mr. Heuschkel has made exhaustive studies of weld cracking and porosity and the procedures necessary to eliminate this major cause of weld failure. A short film and slides were used to illustrate the talk.

A social hour and dinner preceded the technical meeting.

Welded Fabrication

Fort Wayne, Ind.—The *Anthony Wayne* Section held its regular monthly meeting at the Indiana Technical College, Fort Wayne, on April 18th.

La Motte Grover, AWS, Welding Engineer, Air Reduction Sales Co., New York, was the principal speaker. His il-

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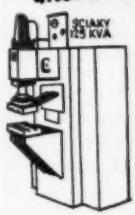

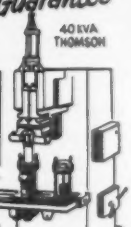

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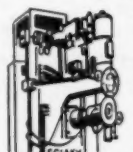

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lustrated subject was on "Welded Fabrication."

Mr. Grover talked on arc welding bridges and buildings and structural work. He mentioned by special engineering and testing agencies many problems had been worked out for welded designs. The combination of architects and designers for structural engineering have played a great part in welded construction. A structure must be designed to have reserve strength and in the building of bridges and rigid frame structures, as much as 30% of the weight had been done away with, by using a welded design, since large gussets and splice plates for riveting were not used. Mr. Grover said butt welds were used wherever possible as they were easier to fit and gave better welds. Butt welds stood more impact better than fillet welds, and full strength of metal was produced in a butt weld. He also said that the welding design in many cases depended on lineal feet of welding and how much was actually needed to reduce the cost of a welded job over riveting. In many buildings and structures some of the material was 3 in. thick and welding has advantages over riveting since no drilling of holes was necessary. After the meeting Air Reduction Sales Co. showed a sound and color picture of inert welding "Aircomatic" which was very interesting and a beautiful demonstration of this type of welding. Forty-three members and guests attended the meeting.

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Annual Spring Symposium

Grand Rapids, Mich.—The Annual Welding Conference and Symposium given by the *Western Michigan* Section was held on Friday, April 18th, at the Grand Rapids Public Museum.

General Chairman of the day was Herbert Knape, AWS, Welding and Process Engineer of the Jarecki Machine and Tool Co.

Fifty-seven registered for the morning event, which included the following:

9.00 A.M. to 10.15 A.M.
Chairman: Glenn Hickok
Subject: Resistance Welding for Production
Speaker: William R. Plummer, AWS, Vice-President, Progressive Welder Sales Co.

10.30 A.M. to 11.45 A.M.
Chairman: R. E. Kemp
Subject: Welding of Aircraft and Jet Alloys
Speaker: William J. Farrell, AWS, Engineering Dept., Sciaky Bros., Inc.

Twenty-six more registered for the afternoon sessions making a total of 83 registrations for the day.

1.00 P.M. to 2.45 P.M. *Chairman:* P. Wagner. J. F. Stitt, AWS, Research and Welding Engineer for the R. C. Mahon Co. gave a very interesting talk and demonstration on "Flame Straightening and Effects of Heat on Welding Structures."

3.00 P.M. to 4.50 P.M. *Chairman:* Chet Voorhorst. The final lecture of the day was given by J. P. Berkeley, AWS, Manager of the Danville Precision Tool Co. Mr. Berkeley had several samples and lectured on Special Fixtures for Automatic Arc Welding.

The day was climaxed by a banquet at the Westminister Presbyterian Church. As trout season opened that week, a film entitled "A Trout-Fisherman's Dream" was shown. The main speaker of the evening was Dr. Guy H. Hill, Director of Office of High School Cooperation, Michigan State College. His subject was "He Who Laughs—Lasts." Dr. Hill is an excellent speaker and all present agreed after hearing Dr. Hill that they would last as they surely laughed and several have asked to have him return for next year's symposium banquet.

Annual Plant Visit

Hartford, Conn.—This year, in conjunction with the Boston, Bridgeport, Springfield and Worcester Sections of the AWS, the *Hartford* Section arranged an exceptionally interesting afternoon and evening on Thursday, April 17th. A guided tour, starting at 2 P.M. through the Bigelow-Sanford Carpet Co. in Thompsonville, covering nine miles and taking 3 hours, was enjoyed by the 80 members and attendants. The members were shown the intricate and complicated operations involved in the manufacture of various types of carpets. The tour started with the incoming raw wool and followed the processing and machining right through to the finished carpet. The guides explained each step as they went along. Cocktails and dinner followed at the Mountain Laurel Inn. District Vice-President E. N. Adams spoke briefly on the activities of his district. I. Morrison, Membership Chairman, spoke on membership drive and congratuled S. Zane, Local Membership Chairman, on the best national record to date. Mr. Morrison entertained the gathering with lots and lots of jokes. A 20-minute address was given by John M. Roddy, Bigelow-Sanford Plant on "Maintenance of Machines and Buildings." This was very good. A 25-minute address was given by William H. Furey of Bigelow's organization and Procedures Division on "The Carpet Industry Then and Now." This was also very interesting.

Preheating for Welding

Houston, Tex.—Arthur B. Tesmen, AWS, Tempil Corp., New York, gave an extemporaneous presentation on "Preheating for Welding" at the April 24th dinner meeting of the *Houston* Section held in Oberholtzer Hall, University of Houston. Eighty-two members and guests heard this illustrated technical talk which covered applications of welding.

A sound color film "Let's Go Fishing" was shown through the courtesy of the Humble Oil Co.

Welding Procedures

Indianapolis, Ind.—"Proper Application of Welding Procedures" was the subject of an illustrated talk given by S. A. Greenberg, AWS, Technical Secretary, at the March 28th dinner meeting of the *Indiana* Section held at Buckley's Restaurant in Cumberland, Ind. Mr. Greenberg followed this with a discussion of welding codes, their current development and general acceptance by various government agencies and the public.

J. G. Magrath, AWS, National Secretary and several members of the New York Section, AWS, who were attending the IAA Convention were also present. Mr. Magrath gave a brief talk on the AWS functions at headquarters, their value and service available to each section and member.

Weldments

Kansas City, Mo.—The April 17th meeting of the *Kansas City* Section was a joint meeting with the American Society for Metals. An excellent meeting was enjoyed with 83 present at dinner and 102 attending the meeting that followed.

Chairman Les Powers introduced the speaker for the evening, G. E. Linnert, AWS, of the Armco Steel Corp. Mr. Linnert spoke on "Stainless Steel Weldments." His excellent talk gave much information on the materials involved in stainless steel weldments. Comments were made on the progress in joining the less-weldable grades, like free-machining Steels. General recommendations were made for selecting the proper grade elec-

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trode to weld standard grades of base metal. A description of the welding properties was given for the newly developed grades of stainless steels, such as the extra-low-carbon materials and the precipitation hardening alloys. He also gave the latest information on methods of cleaning stainless steel weldments.

Allen Wisler, Vice-President, District 6, was present and spoke briefly.

A movie entitled "Playing Ball with the Yankees" was shown and enjoyed by the group.

Resistance Welding Applications

Minneapolis, Minn.—The April 14th meeting of the *Northwest* Section held at the Covered Wagon was an outstanding one from the standpoint of interest in the subject of "Resistance Welding Applications" as discussed by Edwin A. Mallett, AWS, of the Taylor-Winfield Corp. This was evidenced by the fact that the meeting was attended by 92 members and guests. The dinner was preceded by the customary social period known as the Happy Half Hour at which the Air Reduction Co. were the hosts.

After the dinner Mr. Mallett was introduced by Chairman Hixson. Mr. Mallett presented an interesting 90-minute talk on the requirements of product design for assembly by resistance welding. At the close of the talk there was an active question-and-answer discussion of the various phases of the talk.

Symposium on Cutting Stainless Steel

Newark, N. J.—The April 15th meeting of the *New Jersey* Section was devoted to a symposium on cutting stainless steel. The meeting was held at the Essex House in Newark. The first paper by J. R. Kirwin of the Air Reduction Sales Co. on "Flux Injection Cutting" dealt with both the original flux for injection cutting which was suitable for 18-8 and lower alloy materials, and also a new and improved flux for 25-20 and higher alloy materials. Mr. Kirwin mentioned that the chief requirements for flux are low cost, good storage ability, safety in use and effectiveness in fluxing the chromium oxide from the molten metal in the cutting area.

The second paper on powder cutting by J. E. Taylerson, AWS, of the Linde Air Products Co., reported that the use of iron powder produced a very high heat and also provided fluxing of the molten metal in the cutting area. This process was suitable for cutting stainless steel for obtaining quick starts without preheat on carbon steel and for cutting material with a high percentage of refractory constituents.

A short paper by D. C. Mockus, AWS, of the Arcos Corp., on "Oxy-Arc Cutting" described the oxy-arc process and equipment. This consisted of a hollow flux-coated electrode through which oxygen is fed. With this process temperatures at 10,000° F. are reached and a somewhat larger kerf and rougher surface are obtained than with the above-mentioned processes. Operation was very good for piercing stainless steel.

The fourth paper on "Arcair Cutting," presented by M. D. Stepath, AWS, of the Arcair Co., described the Arcair cutting equipment and process. This consisted of a carbon electrode and high-velocity jet of air which serves to blow the molten metal created by the arc out of the reaction zone. In a few cases a flux-coated electrode is employed. It was pointed out that the cut or gouge is made so quickly that very low temperature increases and very little distortion is noted in the base plate. A temperature of 250° would be reached, whereas with other cutting processes this temperature would be from 600 to 700°.

G. E. Bellew, of the Air Reduction Sales Co., led the discussion.

An extra added feature was the showing of a 16-mm. sound film on "Events in Madison Square Garden."

Repairing Tools and Dies

Olean, N. Y.—Thirty-eight members and guests attended the April 21st meeting of the *Olean-Bradford* Section held at the L'Alcove Castle Restaurant, Olean, N. Y.

Following the dinner, Herbert Rogers, Chairman of the Section, introduced W. W. Shackleford, Regional Manager for Eutectic Welding Alloys Corp. Mr. Shackleford gave a lecture on repair and building of dies by welding. Following the lecture slides were shown on repairing tools, such as milling, cutters, drills and broaches with their low-temperature welding alloys.

Through the courtesy of the Abbott Machine Co. and Edward C. Straub, AWS, the meeting was adjourned to their shop, where Mr. Herrick and D. Erhart, AWS, District engineers for Eutectic, demonstrated their new Chamfer Trode. It is a reversed rod used for chamfering, cutting and gouging steel and cast iron. The atomizing action of this electrode leaves the base metal relatively cold.

The next meeting will include a plant visitation.

Submerged Arc Welding

Peoria, Ill.—Harold Baldwin, AWS, R. G. LeTourneau, Inc., spoke extemporaneously on the subject "Application and Savings with Manual Submerged Arc Welding" at the April 16th dinner meeting of the *Peoria* Section held at the Sazarac Restaurant, this city. Mr. Baldwin's remarks covered new methods, applications and processes. The meeting was well received and numerous questions were asked during the meeting. A short discussion followed. There was an attendance of 83 at the meeting.

Inert Arc Welding

Phoenix, Ariz.—The regular monthly dinner meeting of the *Arizona* Section was held at the Hotel Westward Ho, on April 16th with over forty members and guests present.

The principal speaker of the evening was R. A. Hay, AWS, Process Service Representative of the Linde Air Products Co., Los Angeles, who spoke on "New Developments in Gas-Shielded Arc Welding." He also presented a film entitled "A Study of Arcs in Sigma Welding."

Mr. Hay's background well qualified him for his presentation which was very interesting as well as unusually informative.

The meeting was presided over by the Vice-Chairman, J. August Rau, in the absence of Chairman Arthur Tesmer.

Welding Clinic

Richmond, Va.—A Welding Clinic was held on April 17th, 18th and 19th by the *Richmond* Section, attended by more than a thousand people. The efforts of the Section in bringing before the public this unique exhibition were crowned with great success. It was hard work with limited equipment and time. Good publicity work was done by Ben Paxton of the local TV station WTVR of Richmond, who responded magnificently.

The Clinic showed the visiting public what Richmond has to offer, as all of the booths at the CAP Hangar at the Byrd Airport were occupied by local exhibitors. The visitors were very satisfied and greatly approved of it.

List of exhibitors included: Capital City Iron Works; Arcet Equipment Co.; Old Dominion Iron & Steel Corp.; Virginia Welding Supply; Richmond Engineering Co., Inc.; Sydnor Pump and Well Co.; Leo A. Kramer; Welders Supply Co.; Southern Oxygen Co.; A. C. Worley; W. B. Goode Co.; Froehling &

Robertson, Inc. (Industrial analysts); Lawton Schrader Services; and Mutual Boiler & Machinery Ins. Co.

This was something new for Richmond and the response resulted in a wide representation in the visitors who showed intense interest in the many phases applicable to welding.

Structural Steel Welding

Rochester, N. Y.—La Motte Grover, AWS, Welding Engineer with the Air Reduction Sales Co., was the guest speaker at the April meeting of the *Rochester* Section held at the Rochester Turners Club. Mr. Grover has been associated with Air Reduction Co. for the past 13 years, assisting structural engineers, shipbuilders, railway car builders and other industries in developing and controlling design and welding operations. He is a member of the Board of Directors and chairman of various committees of the AWS.

Mr. Grover pointed out that welding in building construction has not advanced as rapidly in late years as it should have due to the scarcity of adequate design engineers and fabrication contractors familiar with the various building codes, etc., and the acceptance of such construction by the consumer. However, he feels that satisfactory progress is being made in this field. He gave a very impressive and educational talk with the use of many slides showing different types of welded design and fabrication of buildings, bridges, etc. He pointed out that welded construction usually eliminates much weight and fabrication cost and is well received anywhere due to the absence of noisy riveting hammers.

At the finish of his talk, many questions were asked and Mr. Grover expertly answered all.

Preceding the meeting, a delicious roast beef dinner was enjoyed by many.

Frank Commisso, Senior Golf Pro of a local country club, was the coffee speaker.

Discussion on Welders Qualification

Salt Lake City, Utah.—Due to the interest in welders' qualifications of many of the industries in the Salt Lake area a meeting of the *Salt Lake City* Section was held on April 15th, in Binkeland's Cafe for the purpose of going over the requirements for welding qualification of both employers and operators.

Ray Potts, AWS, field representative for the Lincoln Electric Co., conducted the meeting and gave an introductory talk on the necessity of testing procedures and operators. He then introduced the other speakers.

The first speaker was Fred Thomas, AWS, who spoke on "How to Become Qualified to Make ASME Vessels in Your Shop." Mr. Thomas is an ASME inspector in the Salt Lake area.

Mr. Thomas discussed the various requirements of a shop; such as design, fabrication inspection and reports necessary to construct an ASME vessel. He then pointed out the necessity for following definite outlined procedures if vessels are to be given the code stamp.

The final speaker of the evening was Darwin Christofferson, AWS, Welding Engineer of the Chicago Bridge & Iron Co., Salt Lake City plant. His subject was entitled "Qualification of Welders," and was broken down in three main parts. Large charts were used to point out the items in each part.

Part I, entitled "Requirements of Employers," covered the necessity for investigating procedures, providing adequate designs along with good fabrication and adequate inspection facilities. It was pointed out that the procedure specification and joint welding procedure are necessary so that customers, inspectors, welding engineers and everyone concerned will be familiar with what is required and can work accordingly.

Part II covered the requirements of manual welding operators. This part covered the preparation, identification, cutting and bending of each type of test plate. Diagrams were used to show the bending jig along with the method of bending each specimen. The test results required were discussed along with the requirements for retests, period of effectiveness, and records.

Part III entitled "Requirements for Automatic Welding," was intended to show the requirements for qualification of automatic welding operations and to show the differences in the various codes (AWS, API-ASME and ASME) with regards to procedure qualification. It was mentioned that the methods for testing automatic test plates were identical with the requirements of manual procedure test plates. It was suggested that more investigation is necessary to set up qualification tests for automatic operators.

The talk was concluded with the presentation of a number of slides showing photographs of actual test failures showing various types of defects along with good welds, in both procedure and operator tests. Slides were also presented to show various report forms and procedure specifications along with examples of the various inspection methods.

The meeting with an attendance of 73 was closed after a discussion with the group.

Cutting Armor Plate

San Francisco, Calif.—On April 28th the *San Francisco* held its regular meeting which was preceded by a roast turkey dinner at the Engineers Club. Directly after dinner Lt. Edward Moody presented a coffee talk on "Good Money for Bad Paper." Lt. Moody is connected with the Check Detail of the San Francisco Police Department and his subject proved of interest to all those present.

Charles Robinson, AWS, Special Technical Representative of the Air Reduction Pacific Co., presented a talk on "Oxyacetylene Cutting of Armor Plate and Other Alloy Steels" illustrated with black and white slides. Mr. Robinson gave a review of the techniques and procedures of gas cutting with the latest data on rolled armor plate; helpful hints on cutting procedures, including a discussion of fuel gases, proper speeds, pressures and other useful up-to-date information.

A question-and-answer period at the end of the discussion was in order.

Planning for Welding

San Francisco, Calif.—Seventy-three members of the *San Francisco* Section enjoyed a roast beef dinner on March 24th at the Engineers Club, San Francisco. Directly after dinner, Robert Barrington, Information Supervisor, Pacific Telephone and Telegraph Co., gave a demonstration of the operation of the television microwave relay.

The Section was fortunate to have present Charles H. Jennings, President of the AMERICAN WELDING SOCIETY and Manager of the Arc Welding Engineering Dept. of the Westinghouse Electric Corp., Buffalo, N. Y., who talked on "Planning for Welding." In his usually able manner, Mr. Jennings presented a discussion of product design, welding processes and equipment, testing and other significant factors to be considered in planning economic and high-quality welding operations.

Welding Stainless Steels

Wichita, Kan.—George E. Linnert, AWS, Research Welding Metallurgist, Armco Steel Corp., Baltimore, Md., was the speaker at the April 14th dinner meeting of the *Wichita* Section held at the Polar Bear Coral Room in Wichita. Mr. Linnert's subject "Recent Developments in Welding Stainless and Heat-Resisting Steels" covered materials involved in stainless-steel weldments more than the welding processes. A few comments were made on the newer welding and cutting processes used on high-alloy steels. Progress in joining the less weldable grades, like free-machining steels, was described. The newly developed grades of stainless steels such as the extra-low-carbon materials and the precipitation-hardening alloys were reviewed and a description given of their welding properties.

Applied Welding Engineering

York, Pa.—Simon A. Greenberg, AWS, Technical Secretary was the guest speaker at a dinner meeting of the *York-Central Pa.* Section held on April 9th. Dinner was served at the Hotel Yorktowne. Lecture was held in the Engineering Society Bldg. A 35-mm. slide film strip projector with narration on record, played on a 33 1/3 rpm. record player, was shown in conjunction with Mr. Greenberg's excellent address on "Applied Welding Engineering." The film is based on industrial experience and is illustrated by typical actual weldments.

Mr. Greenberg has been associated with the AWS since 1942. He is responsible for the preparation and correlation of all society activities in the compilation of welding codes, standards and specifications, and the promotion of use of these standards for more efficient welding.

LIST OF NEW MEMBERS

Effective April 1, 1952

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Bennett, W. F. (C)
Broutin, K. L. (C)
Jones, L. H. (C)
Lehmann, L. A. (C)
Long, Randall F. (B)
Phillips, E. P. (C)
York, J. L. (C)

BOSTON

Burke, Alan W. (C)
Corcoran, J. Roger (B)
Dougherty, J. Bruce (C)
Nyberg, Frederick A. (C)

BRIDGEPORT

LaRiviere, Hector E. (C)

CHATTANOOGA

Locke, James H. (B)

CHICAGO

Cox, Charles N. (C)
DeSanto, Joseph (C)
Hale, Russell S. (C)
Kaikaris, John C. (C)
Luga, Theodore F. (C)
Robinson, R. W. (C)
Walker, Richard W. (C)

CINCINNATI

Gordon, Raymond E. (C)

CLEVELAND

Cantelmo, V. M. (C)
Daywalt, H. William (C)
Dixon, Ralph W. (C)
Heller, John F. (C)
Hennig, Heinz G. (C)
Hillier, John S. (C)
Holland, James W. (C)
Horst, Robert V. (B)
Ichak, George B., Sr. (C)
King, S. R. (B)
Kleinholz, Nicholas (B)
McMillan, John E. (C)
Mellini, Anthony Robert (C)
Schneider, Raymond (C)
Vergith, George S. (B)

COLORADO

Bartlett, Sidney (B)
Montgomery, John (B)
Pardee, Victor J. (B)
Woolf, E. Allen (B)

COLUMBUS

Jones, Archer B. (B)
Lamb, H. O. (B)

DAYTON

Appenzeller, Robert C. (C)
Bartley, William R. (C)
Stegmeier, Kenneth C. (B)

DETROIT

Bastian, Carl F. (B)
Clark, Charles W. (B)
Edward, Robert Lewis (C)
Harrington, Max H. (B)
Killutat, Lorenz E. (B)
Miskokomon, Harry (B)
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Stress Concentrations in Steel Under Cyclic Load

The behavior of stress concentrations in ductile bodies under cyclic load with particular reference to steel pressure vessels. Prepared for the Pressure Vessel Research Committee

By Dr. E. Orowan

1. INTRODUCTION

IT IS often difficult for the designer to recognize the presence of stress peaks in pressure vessels, and to estimate their magnitude; but even if their existence, e.g., at the knuckle of a drum headplate, is known, it is often impracticable to avoid them by local reinforcement or by a change of the design. Since most pressure vessels are made of rolled steel plate, an attempt to keep the stress well below the elastic limit even at the local peaks may make large parts of the vessel greatly overdimensioned. For this reason, it was customary until recently not to take into account the stress peaks explicitly but to rely to some extent on the ductility of the steel, and on the use of generous "safety factors." Considerable plastic deformations occurred frequently at local stress concentrations.

This situation has changed radically during the last decade. Electric resistance strain gages have made it possible to map the strains at points hitherto inaccessible to measurement; increasing pressures and temperatures have demanded stronger steels, which have a lower ductility; and the high price of such steels and of the fabrication, together with the possibility of accurate strain measurements, have led to a tendency to get rid of the traditional high "safety factors" which reflected the unreliable nature of the designer's knowledge, rather than any fickleness of the material or of the working conditions.

Any reduction of the safety factors or of the ductility of the material, however, raises a question of great importance. The steels in use or intended for use are ductile enough to withstand some plastic deformation at undetected stress peaks if the load is applied once only. However, in a pressure vessel the load may be applied many thousands of times, and so the question arises whether the local transgressions of the elastic limit will not lead to fatigue failure. For several reasons, the answer cannot be obtained directly from conventional fatigue test data. First of all, the amplitudes of stress and strain do not remain constant at points of local yielding in a body subjected to cycles of constant load amplitude: owing to strain hardening, they change progressively. The study of the fatigue behavior of the material at local stress peaks, therefore, requires the calculation of the local stress and strain amplitudes and of their change in the course of cyclic loading. It seems that this fundamental problem of fatigue in engineering structures has not been treated so far; the method required for its solution, however, has been developed in its application to the physical theory of fatigue.[1, 2] Part I of the present paper will deal with this point and give a simple graphical solution. It will be seen that the local stress and strain amplitudes tend toward final values which may be reached after the first cycle, or asymptotically approached in the course of continued cyclic loading. The structure can withstand an unlimited number of cycles if the final local stress cycle is a safe one according to conventional fatigue test results.

There is a second reason why the usual fatigue test data cannot provide the information required in pressure vessel design. Many engineering structures subjected to cyclic loading have to withstand millions of cycles; the stress amplitude, therefore, must be below the limiting safe amplitude represented by the horizontal, or nearly horizontal, part of the Wöhler curve (the log S–log N curve), and for some materials this is less than one-half of the elastic limit. It will be seen that the final local stress amplitude at stress peaks where yielding has occurred is generally above one-half of the initial elastic limit; with many materials, therefore, load cycles that produce local yielding cannot be safe. However, the number of load cycles during the life of a pressure vessel may be only a few thousand; one may think, therefore, of admitting load amplitudes that would be unsafe for unlimited numbers of cycles. How many load cycles can be applied at a given amplitude before fracture occurs is shown by the initial sloping branch of the Wöhler curve; however, the high-stress part of this curve is almost always omitted from fatigue tests because the corresponding large amplitudes, being unsafe for high numbers of cycles, are not of a general practical interest. It will be necessary, therefore, to discuss the question of how the number of cycles to fracture depends on the stress or strain amplitude for large strains; this

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will be one of the subjects treated in Part II. Finally, Part III will deal with practical possibilities of increasing the fatigue endurance of pressure vessels, as far as they can be recognized on the present very limited basis of experimental data.

Part I

2. THE FINAL STRESS RANGE AT A STRESS PEAK IS NOT INFLUENCED BY LOCAL PLASTIC YIELDING

We shall consider in this report mainly two types of stress peaks in nonuniformly stressed bodies: the high stress at the top and bottom surface of a bent rod (Fig. 1 (*a*)), and the stress concentration around a notch (Fig. 1 (*b*)). To avoid unnecessary complications, we shall assume that the regions of plastic deformation at the stress peaks are very small, so that the deformation of the body as a whole does not depend significantly on what happens in the small plastic regions. Thus, the deflection of the bent rod in Fig. 1 (*a*) is determined by its elastic bulk alone and is not affected by the progressive strain hardening in the very thin plastic surface layers shaded in Fig. 1 (*a*). If the bending moment varies between fixed limits, therefore, the deflection will also vary between constant extreme values. If the plastic regions are too large to be neglected in this manner, the deformation of the body as a whole will decrease by strain hardening if the range of the load cycles is kept constant; vice versa, the load range will increase if the amplitude of the deformation cycles is kept constant. In either case, it is easy to adapt the results given in the present report to the existing conditions of loading.

Suppose now that the rod in Fig. 1 (*a*) is subjected to a cyclically varying bending moment, and that the elastic limit in thin layers at its top and bottom surface is exceeded at the first application of the maximum moment. It will be seen in Section 4 that the strain hardening during the first load cycle may prevent any further yielding; but even if this is not the case, the material of the surface layers strain hardens progressively in the course of the subsequent load cycles until its yield stress is high enough to prevent further plastic deformation. Thus, the initially plastic regions finally become purely elastic, unless the specimen breaks before this is achieved, or the hardening capacity of the material becomes exhausted (i.e., its true stress-strain curve becomes horizontal). However, once the body has become purely elastic, *the stress amplitude at its initially plastic regions rises to the same value as it would have if the body had been purely elastic from the beginning.* Residual stresses may have been left behind, but they can influence only the mean stress of the cycle, not its amplitude.

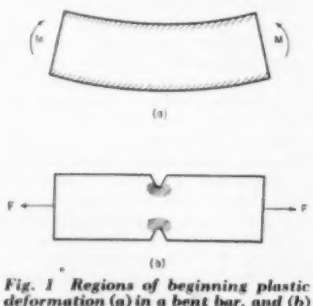

Fig. 1 Regions of beginning plastic deformation (a) in a bent bar, and (b) in a notched rod

This simple and important rule shows that the initial "stress redistribution" by plastic yielding at a local stress peak does not reduce the stress amplitude to which the material is ultimately exposed here if cyclic loading is continued. If the safe amplitude in fatigue is independent of the mean stress, therefore, local plastic deformation does not reduce the danger of fatigue failure. Local yielding can be helpful only if the safe amplitude diminishes with increasing mean stress of the cycle, because, as we shall see later, the mean stress of the local stress cycle in repeated loading is reduced by yielding. However, with most materials the influence of the mean stress upon the safe range is small in the entire range between alternating and repeated load. Unless the material has rather unusual properties, therefore, stress-redistribution by local yielding does not reduce the danger of fatigue failure, for an unlimited number of load cycles.

3. THE PROGRESSIVE CHANGE OF THE STRESS AND STRAIN CYCLES IN THE PLASTIC SURFACE LAYERS OF A ROD IN ALTERNATING BENDING

Suppose that the bending moment acting upon the rod in Fig. 1 (*a*) alternates between the extreme values $+M$ and $-M$, and let curve OPF in Fig. 2 represent the true stress-strain curve of the material with the elastic strains included. Owing to the assumption that the plastic surface layers (shaded in Fig. 1 (*a*)) are very thin, strain hardening in them will not influence the deflection, and the total (elastic plus plastic) strain in the surface layers will alternate between the constant limits OA and $OB = -OA$ (Fig. 2). The first bending carries the plastic deformation in the surface layer along the stress-strain curve to the point P, of which the strain abscissa is OA. When the bending moment decreases after having reached its maximum $+M$, the plastic strain in the surface layers first remains constant, while the elastic strain decreases along the elastic line PC (of which the gradient is

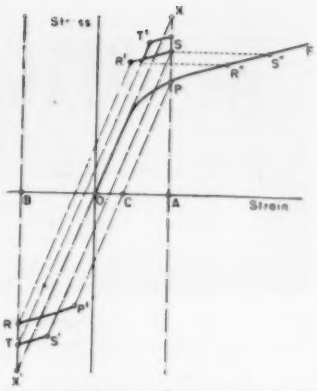

Fig. 2 Variation of stress and strain at a plastic stress peak under alternation load in the absence of Bauschinger effect

Young's modulus). When $M=0$, the rod is straight and the surface strain zero; this is the result of the tensile plastic strain OC in the lower surface layer being compensated by the compressive residual elastic strain $-OC$. When M becomes negative, the stress-strain point moves further down along the elastic line toward negative values of the stress, until compressive plastic yielding starts. It is a general property of metals that, after tensile straining beyond the elastic limit, plastic deformation in compression starts at a stress lower than the tensile yield stress last reached; this softening by a preceding plastic deformation of the opposite type is called the Bauschinger effect, after its discoverer, the Munich engineer J. Bauschinger.[2] To avoid unessential complications, we shall assume for the present that there is no Bauschinger effect; plastic deformation in compression, then, starts at the point P' which is as much below the abscissa axis as is P above it. Furthermore, in the absence of a Bauschinger effect the yield stress ought to rise with increasing compressive strain at the same rate as it would rise in tensile straining if this were continued beyond the point P; in other words, the stress-strain point ought to follow the curve $P'R$ obtained from curve $P'F$ by a rotation of 180 degrees around the point C in the plane of the figure. At the point R, the surface strain and the bending moment reach their maximum negative values OB and $-M$, respectively, and plastic compression ceases. As the moment increases toward positive values, the surface stress-strain point moves along the elastic line RR' until, at R', the previous absolute maximum of the yield stress is reached again and tensile yielding starts. Stress and strain then follow the curve $R'S$, identical with the segment $R''S''$ of the stress-strain curve OPS, until, at S, the surface strain again reaches its maximum positive value corresponding

to the bending moment $+M$. With increasing number of load cycles, obviously, the stress-strain point for the surface layer follows a hysteresis spiral OPP' RR' SS' $T\ldots$, of which the individual loops become narrower and longer in the course of time; finally, they converge toward the elastic line XOX' through the origin. Thus, as the material in the surface layers hardens, its yield stress rises toward the value $AX = -BX'$, which is the stress that would arise in the surface layer under the bending moment M if the rod were perfectly elastic. In other words, the material raises its yield stress by strain hardening to the value AX that is just sufficient to prevent any further plastic deformation, provided of course that no fracture occurs during the process and that the strain hardening capacity of the material does not get exhausted (= its stress-strain curve does not become horizontal).

Figure 2 becomes much easier to manipulate if it is transformed by graphical shearing* along the horizontal, in counterclockwise direction, so that the elastic lines PP', RR', etc., become vertical. Figure 3 is the result of such a transformation by shear of Fig. 2; the shearing amounts to a deduction of the elastic strain from the total strain, so that all abscissae in Fig. 3 represent plastic strains alone in the surface layers. By the shearing process the dash-dotted verticals AX and BX' in Fig. 2, representing the upper and lower limits of the strain, become inclined; these lines, AX and BX' in Fig. 3, will be called the strain limit lines. In Fig. 3, the points P', R' or S' where plastic deformation starts again are vertically below or above the points P, R of S where plastic deformation has stopped previously. Since P' is as much below the abscissa axis as is P above it, P' is the intersection of the vertical through P with the auxiliary line AX' which is a mirror image of AX with respect to the abscissa axis. Similarly, the auxiliary line BX makes it easy to find the point R', etc.

A further simplification is obtained by folding the lower half of Fig. 3 around the abscissa axis over its upper half; the result is shown in Fig. 4. After folding, the strain limit lines AX and BX' coincide with the auxiliary lines AX' and BX, respectively, and the previously scattered segments OP, $P'R$, $R'S$, etc., of the plastic stress-strain curve fit together to form the continuous zig-zag $OPRS$.

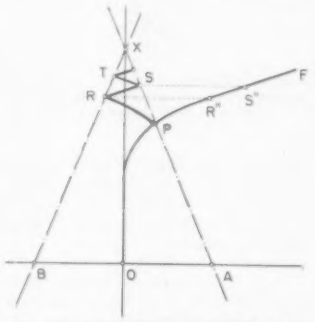

Fig. 4 Zig-zag curve showing the increase of the absolute value of stress and the accompanying decrease of the plastic strain amplitude at a plastic stress peak under alternating load in the absence of Bauschinger effect

Figure 4 shows directly how the variation of the stress and of the plastic strain in the surface layers in the course of alternating bending is obtained graphically. The construction embodied in the figure is as follows: (*a*) Plot the true stress-plastic strain curve OPF of the material (its initial tangent is vertical, since it does not contain the elastic strain); (*b*) plot the points A and B on the abscissa axis between which the total (elastic plus plastic) strain in the surface layer oscillates; (*c*) plot the point X giving the stress that would be present in the surface layer if the material were purely elastic; (*d*) construct from consecutive pieces of the stress-strain curve OPF the zig-zag $OPRST\ldots$ ascending between the strain limit lines AX and BX. The zig-zag gives the variation of stress and plastic strain in the surface layers during alternating bending. It shows that the plastic strain amplitude of the cycles decreases and finally vanishes, while the stress amplitude increases and tends toward OX, the stress amplitude that would be present in a purely elastic rod.

Obviously, the material at the surface will be in a safe range with respect to fatigue if the stress amplitude OX is a safe one. Thus, as it was remarked in the preceding Section, the initial yielding in the surface layer does not reduce the stress amplitude to which the layer will be finally exposed. In addition, the mean stress of the cycle also remains invariant (equal to zero) in the particular case of alternating bending.

4. THE PROGRESSIVE CHANGE OF THE LOCAL STRESS AND STRAIN AMPLITUDES IN GENERAL CYCLIC BENDING, AND IN REPEATED BENDING

In the general case of cyclic bending, the bending moment varies periodically between an upper limit M_1 and a lower limit M_2. If $M_2 = 0$, the case is that of repeated bending.

Obviously, the only change in Fig. 2 is that now the point B and the dash-dotted vertical BX' can lie anywhere to the left of point A. After shearing, this figure goes over into Fig. 5; in the special case of repeated bending, B coincides with the origin O, and Fig. 6 is obtained.

Figures 5 and 6 show an interesting possibility that does not exist in purely alternating bending. Consider Fig. 6 where the two stress-strain curves OP_1F_1, and OP_2F_2 stand for two possible positions of the stress-strain curve relatively to the apex Z. For a given material (given stress-strain curve), the relative position OP_1F_1 corresponds to a high stress (Z above the stress-strain curve), and OP_2F_2 to a low stress. For a given applied stress, OP_1F_1 would represent a soft and OP_2F_2 a hard material. If the stress-strain

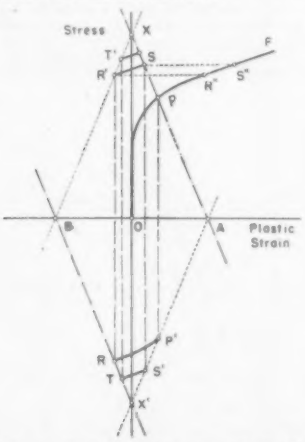

Fig. 3 Variation of stress and plastic strain (elastic strain not included) at a plastic stress peak under alternating load in the absence of Bauschinger effect

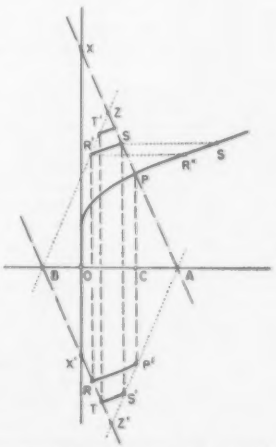

Fig. 5 Same as Fig. 3, but with a positive mean stress of the cycle

* Shearing a figure means to distort it by simple shear parallel to a given direction. In the present case, the shear is parallel to the abscissa axis; it amounts to deducing from the abscissa of any point of the figure the elastic shear strain corresponding to the ordinate of the point, as given by the elastic line OX in Fig. 2.

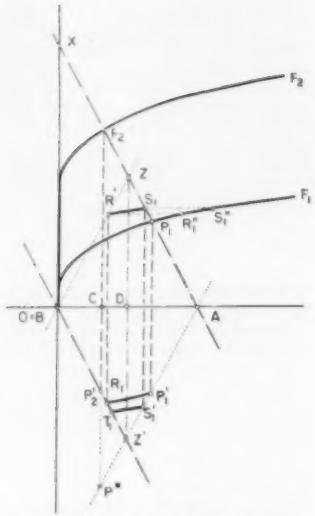

Fig. 6 Same as Fig. 3, but for repeated load. With the higher stress-strain curve, plastic deformation would cease after the first application of load

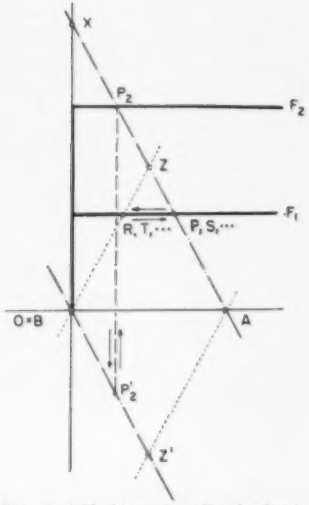

Fig. 7 "Shaking down" of plastic deformation in an ideally plastic material under repeated load

curve OP_2F_2 (Fig. 6) intersects the upper strain limit line AX above its point of intersection Z with the "folded" lower strain limit line BZ, the lowest value to which the stress can drop (when the bending moment reaches its minimum M_2) is that given by the point P'_2 which is vertically below P_2 on the original lower strain limit line BZ'. The point P'_2, however, is still above the point P^* on the auxiliary line AZ' where reverse plastic deformation would begin. That is to say, there can be no plastic deformation after that produced by the first maximum load in the first cycle; in the following cycles the stress oscillates between the points P_2 and P'_2 and the strain is purely elastic.

Prager and Symonds[4] have called the cessation of plastic deformation in such cases the "shaking down" of the plastic strain to the final value OC' (Fig. 6). They have investigatd such shaking-down processes in structural engineering, with the assumption of an ideally plastic material, i.e., one that shows no strain hardening and thus has a horizontal line for its plastic stress-strain curve. Figure 7 shows that plastic deformation would never tend to cease in such a material if its yield stress was below the apex Z of the strain limit lines that correspond to the given load: the deformation could shake down to a purely elastic one only if Z were below the horizontal line representing the stress-strain curve of the ideally plastic material. With strain hardening real materials, the situation is quite different. Even if the stress-strain curve intersects the upper strain limit line below the apex Z, the plastic strain "shakes down" asymptotically to a final value by strain hardening, unless the process is interrupted by fracture.

It is easy to recognize from Figs. 5 and 6 that, no matter what the position of the stress-strain curve, the final stress amplitude in the surface layers is always the same, namely, the vertical distance between the upper and lower strain limit lines AX and BZ'. On the other hand, the mean stress of the final stress cycle does depend on the plasticity of the material. If there is no plasticity, the stress, like the load, oscillates in Fig. 6 between a maximum and zero. If the stress-strain curve intersects the upper strain limit line above the apex Z, the mean stress of the subsequent (purely elastic) cycles is given by the mid-point between P_2 and P'_2. If it intersects below the apex Z, a state is asymptotically approached in which the stress oscillates between $ZD = OX/2$ and $-OX/2$, and the mean stress is zero.

At first glance, it might seem that the last case was a favorable one and that the plasticity of the material had the beneficial effect of reducing the highest stress in the surface layers from OX to $OX/2$. In reality, however it is just the other way around. The important factor for fatigue is the stress amplitude of the cycle, and this is not reduced in the long run. The mean stress has in general little influence; the real difference between the cases represented by curves OP_1F_1 and OP_2F_2 in Fig. 6 is that, for the more plastic material represented by the former curve, the final stress range is larger compared with the initial elastic limit of the material, and thus the conditions are further removed from safety.

This conclusion is strikingly illustrated by experiences made with railroad signal wires in Britain. The first official standards for such wires demanded a ductility above a given minimum and an ultimate stress not exceeding a certain limit; this demand corresponded to the instinctive feeling that, in order to withstand frequent bending around the small guiding pulleys, the wires must be made of very ductile material. When the standards were introduced against the opposition of the wire manufacturers, frequent wire fractures indicated that, as so often, instinct was misleading. The standards were modified so as to demand an ultimate stress not below a given minimum and a reduction of area not exceeding a certain limit, and the trouble disappeared.

5. THE BAUSCHINGER EFFECT

As already mentioned, the yield stress of metals in compression after preceding yielding in tension is lower than the tensile yield stress last reached; similarly, it is easier to start tensile yielding after compressive yielding than to continue the latter. This phenomenon, which is due to microscopic and submicroscopic internal stresses developed during plastic deformation, is the Bauschinger effect. If it is taken into account, the stress-strain point of the surface layer in the alternately bent rod follows the path PCR' (Fig. 8) instead of the path $PCP'R$ assumed in Fig. 2. Similarly, the onset of yielding in the consecutive cycles is not sharp as assumed in Figs. 2 to 6 but gradual, and yielding always sets in at lower stresses than it would in the absence of the microscopic internal stresses responsible for the Bauschinger effect. As a consequence, the hysteresis spiral has in reality the shape shown in Fig. 8, instead of that as-

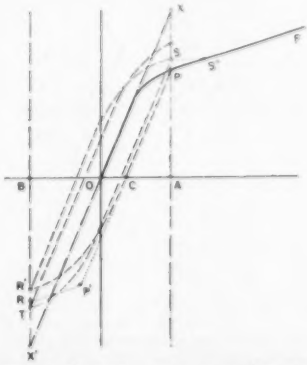

Fig. 8 Variation of stress and strain at a plastic stress peak under alternating load with Bauschinger effect

sumed in Figs. 2 or 3. Instead of the simple zig-zag curve of Fig. 4, we now obtain a more complex figure of the type shown in Fig. 9; owing to the Bauschinger effect, the yield stress at the minimum value of the bending moment (on the line BX) may even be lower than it was at the preceding maximum (on the line AX). Thus, the corners of the zig-zag may be arranged as in Fig. 10, where they are connected with straight lines neglecting the dip between two consecutive corners. However, the consecutive stress-strain points corresponding to the maximum values of the bending moment still rise on line AX toward the apex X, although possibly much slower than it would correspond to a static stress-strain curve, because a large part of the strain hardening acquired during the tensile or compressive part of a cycle is wiped out by the Bauschinger effect during the subsequent strain reversal. Thus, if the yield stress is plotted as a function of the total absolute strain in reversed straining, the curve obtained is much flatter than the static stress-strain curve, and it may well become nearly horizontal for some materials. However, unless it really becomes horizontal, so that the Bauschinger effect ultimately cancels strain hardening, the effect can only slow down the rise of stress in the surface layer in cyclic bending but cannot reduce the limiting stress which is that produced by the given load in a body of the same shape but of purely elastic material.

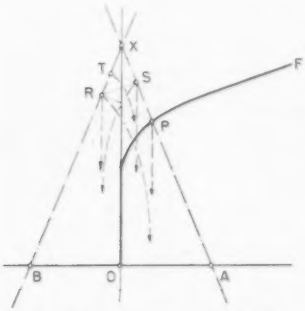

Fig. 9 Zig-zag curve showing the influence of the Bauschinger effect upon the rise of the absolute value of stress at a plastic stress peak under alternating load

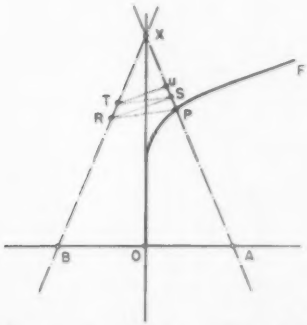

Fig. 10 Same as Fig. 9, with the Bauschinger effect strong enough to cause a decrease of yield stress during the reverse half of the cycle

On the other hand, the "shaking-down" process mentioned above is greatly modified by the presence of the Bauschinger effect which is not included in the picture of the ideally plastic solid. Experience shows that, e.g., after a moderate amount of tensile plastic straining, non-elastic compression becomes noticeable, as a rule, as soon as the stress becomes slightly compressive. Thus, mechanical hysteresis may become important as soon as the material comes under stress opposite to its last plastic strain, even if, as in curve OP_2F_2, Fig. 6, the plastic strain would shake down to a final value after the first cycle in a material free from the Bauschinger effect.

6. OTHER CASES OF STRESS INHOMOGENEITY

The preceding considerations apply to the thin surface layer of a bent rod in which the elastic limit has been exceeded in the course of cyclic bending. However, the corresponding treatment of other types of stress peaks in nonuniformly stressed bodies is very similar.

We still retain the assumption that the plastic regions of stress concentration are so small that their influence upon the deformation of the bulk of the body is negligible, so that the body containing the stress peak is substantially elastic and carries out cycles of constant strain amplitude under load cycles of constant amplitude.

The essential difference between the stress peak at the tip of the notch, Fig. 1 (*b*), and that on the surface of the bent rod, Fig. 1 (*a*), is that in the second case the total (elastic plus plastic) strain in the surface layer is constant and independent of the plastic strain for any given value of the load (= of the bending moment); in the case of the notch, on the other hand, plastic yielding at its tip leads to elastic stress relaxation not only in the yielded volume but also in its purely elastic surroundings. Thus, the behavior of the stress concentration at the tip of the notch can be schematized in the way shown in Fig. 11. Here, P is a plastic body; in addition to having its own elasticity, it is connected with the main body of a bent rod, R, by flexible purely elastic arms E. This arrangement corresponds to the behavior of the notch root in two respects: first, owing to the two lever arms E, the strain in P may be much higher than at the surface of R; second, it is not the strain in P that is constant for a given load L, but the sum of the elastic

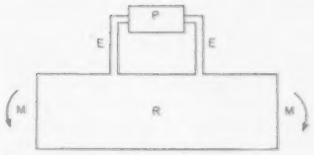

Fig. 11 A more general case of a stress peak. R is an elastically bent bar, E elastic arms, P a plastic rod

and plastic strains in P and E. This scheme shows that the more general case can be treated exactly as the simpler one of the surface layer in the bent rod. In Fig. 3, OX is now the stress that would exist at the notch root if the body were purely elastic and the load had its maximum value; OX' is the corresponding stress for the (algebraic) minimum of the load. OA is the total strain (plastic and elastic) in the plastic region plus the elastic strain in its elastic surroundings represented in the scheme Fig. 11 by E, for maximum load; OB, the corresponding total strain for minimum load. The graphical method itself remains the same.

Naturally, all this involves several drastic simplifications. In reality, stress and strain are not constant in the plastic volume at the notch root, as they are not constant in the surface layer of the bent rod either. The simple graphical method shown in Figs. 3, 4 and 5, therefore, is quantitatively correct only in certain particularly simple cases; in general, it gives only a qualitative picture of the process. An exact treatment, however, would usually be very complex and possibly not worth the work involved.

Another complication not taken into account in the above considerations is that the plastic volume, as a rule, does not remain constant during the cyclic loading but increases, decreases or migrates to other points of the loaded body. A very simple example of this is the bending of the thin rod in Fig. 12 with a large constant strain amplitude. Initially, only the shaded region next to the support where the bending moment is highest, suffers plastic bending. A very simple example of this is the bending of the thin rod in Fig. 12 with a large constant strain

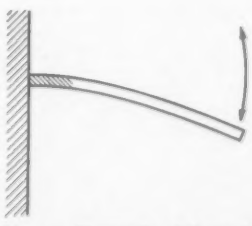

Fig. 12 Plastically deformed region at the rigidly supported end of an alternately bent rod

amplitude. Initially, only the shaded region next to the support where the bending moment is highest, suffers plastic bending. As it strain hardens, however, the bending moment required for the given deflection increases, and the elastic limit is exceeded in neighboring parts of the rod, so that the plastic region gradually extends toward its free end.

7. CONNECTION WITH THE PHYSICAL THEORY OF FATIGUE

The preceding Figs. 3 to 6, 9 and 10 are very similar to diagrams used by the present author in his general theory of fatigue.[1,2] In order to avoid the impression that the present considerations involve in any way theoretical assumptions about the physical nature of the fatigue process, it should be pointed out that the only point of contact between the above graphical calculations and the physical theory of fatigue is the use of the same mathematical method, with diagrams which look very similar but have a different physical meaning. The present paper aims only at the calculation of the amplitudes of stress and strain in small regions of local stress concentration where yielding occurs; how the material reacts to these stresses and strains is regarded as a question that should be investigated experimentally. In the general theory of fatigue, on the other hand, the problem is to explain the observed fatigue behavior of materials under cycles of constant stress or strain amplitude, on the basis of their unavoidable structural inhomogeneity and of the assumption that continuing plastic deformation causes progressive strain hardening. It is shown in the general theory of fatigue that these two assumptions are sufficient to explain the main features of fatigue phenomena, without requiring any specialized assumption about the nature of the structural changes taking place during the fatigue process.

In the theory of fatigue mentioned, the mathematical method underlying the above Figs. 3 to 6, etc., is used for investigating the conditions under which a fatigue crack can spread or arise. If a crack is already present, it can be treated exactly like the notch in Fig. 1 (*b*). From the knowledge of the elastic characteristics of the locally yielded region and its elastic surroundings, the development of the stress and strain amplitude at the root of the crack can be deduced by means of Fig. 4, if the load is an alternating one, or by means of Fig. 5 if the load cycle has a nonvanishing mean stress. Let us assume the former case. The stress-strain curve *OPF* does not describe the behavior of the metal completely: we must also know its fracture criterion. The metal may break when the highest tensile stress reaches a critical value; or, what is more in keeping with general experience in fatigue, it may break when the total absolute strain has reached a limit. In either case, fracture will occur when the stress-strain point on the curve reaches a final point F; that is to say, when the zig-zag curve derived from the stress-strain curve reaches the height of the point F. Now, if the applied load amplitude is low, the strain limit lines are close to the origin and their apex X (in Fig. 5, Z) has a low position. If X is below the height of F, the stress or the total absolute strain can never reach the values corresponding to F; plastic deformation ceases as the point X is approached, and fracture does not occur: the load range is a safe one. If, on the other hand, the load amplitude and thus the position of X is high, the point F and the point of the same height and same absolute strain on the zig-zag curve is reached before plastic deformation would cease at X, and the overstressed region at the root of the crack breaks. In this way, the crack propagates and finally leads to the fracture of the entire specimen.

The formation of the first local crack in an unsafe range* must take place in a similar way. Every material must contain regions where plastic deformation is easier than elsewhere. If local yielding occurs in cyclic loading, both the absolute strain and the yield stress increase gradually at such points. If the increase of the yield stress can stop further plastic straining before the critical value of the fracture strain is reached, no crack is formed; otherwise, the plastic region finally cracks and the crack may start to spread. If the elastic and plastic characteristics of the "soft" region are known, as well as its fracture criterion, the question whether a given load amplitude is a safe one can be investigated with the graphical method described above.

The fundamental questions of the origination and propagation of fatigue cracks will not be discussed in this report. The graphical method will be used only for finding the stress amplitudes and mean stresses in highly stressed microscopic regions which are then treated as small fatigue specimens on the basis of experimental fatigue data.

Part II

8. OBSERVED FATIGUE BEHAVIOR OF BENT AND NOTCHED SPECIMENS

There are two types of fatigue test that realize the cases discussed in Part I: these are fatigue tests with cyclically bent specimens, and tests with notched specimens.

The problem of the nearly elastic bent rod is by far the most extensively investigated one in fatigue testing: every rotating beam fatigue test exemplifies the process discussed in detail in the preceding Part I. Applied to such tests, the theory leads first of all to a conclusion so simple that it is usually taken as granted. It is that, in spite of the nonuniform deformation of the bent beam, and the concentration of plastic deformation in its surface layer when its elastic limit is exceeded, the fatigue limits derived from rotating beam tests are not essentially different from those obtained with specimens uniformly stressed in push-pull machines. In fact, the difference is usually within the limits of accuracy of the measurement. This confirms that the plastic deformation in the surface layer of the beam cannot modify the safe range of stress. According to Part I, fracture should occur in relatively highly loaded rotating beams a little later than in uniformly stressed specimens, because it takes some time for the maximum stress amplitude to develop by strain hardening. The delay, however, is probably negligible in most cases.

Another relevant field of experimental investigation is that of fatigue testing with notched specimens. The "notch sensitivity" of materials in cyclic stressing must not be confused with notch brittleness (notch sensitivity in ordinary fracture); there is no direct connection between the two properties. In fatigue, a material is said to be notch sensitive if the presence of a notch reduces the limiting safe load amplitude for a given cross-sectional area. In notched bar fatigue testing, usually rotating beam machines are used with specimens provided with circumferential V-notches; for purposes of comparison with unnotched specimens, a fictitious maximum bending stress is calculated from the elementary theory of bending for the cross section within the notch, the stress concentration due to the notch being disregarded. If the general results developed in Part I were directly applicable, the outcome of fatigue tests with notched specimens would be very simple: the safe load amplitude would be reduced by the elastic stress concentration factor of the notch. In other words, if in a geometrically similar but purely elastic specimen the stress at the tip of the notch is q times higher than at the same point in the absence of the notch, the notch ought to reduce the limiting safe range of load by the factor q, according to the direct application of the mechanical theory: no matter how large the initial plastic deformation at the notch root, the metal there ought to harden under cyclic stressing until it is perfectly elastic, and then the stress amplitude ought to be the same as if no plastic deformation had ever taken place. Since the stress concentration factor depends only on the shape but not on the material of the specimen, all materials ought to show the same notch sensitivity, unless they cease to strain-harden before the stress reaches the endurance limit. This may conceiv-

* I.e., unsafe for an unlimited number of cycles.

ably occur if the stress concentration is confined to a very small volume (see below).

All this is in striking contrast with the observed facts. First of all, the factor by which the safe load range is reduced by the notch is usually much smaller than the elastic stress concentration factor; it may be quite close to unity. Further, different materials behave quite differently in this respect: some are fairly notch-sensitive, others are not. Remarkably (and this is rather in agreement with the theoretical considerations) there is no general connection between ductility and notch-sensitivity: a relatively brittle material like cast iron is almost indifferent to small sharp notches as far as its fatigue endurance is concerned.

Thus, one is confronted with a remarkable contradiction. On the one hand, the general treatment embodied in Figs. 4, 5 and 6 leads to the rigid conclusion that at given load a notch or crack of elastic stress concentration factor q is bound to increase the final local stress amplitude by the factor q. On the other hand, the experimentally observed effect of a notch upon the safe load amplitude is usually far less than would correspond to its elastic stress concentration factor, and often very small indeed. The only possibility for explaining this discrepancy seems to be to assume that a material behaves differently if it is stressed within a very small volume only; in other words, to attribute the observed low notch sensitivities to a size effect.[5] It is well known that thin fibers of glass and of many other materials are far stronger than thick rods; similarly, the strength and thus the fatigue endurance may be higher if the stress is confined to a small volume, e.g., at the root of a sharp notch. There are several other conceivable causes for the size effect. If the plastically strained volume and thus the magnitude of the slip movements are very small, the material may not suffer any progressive structural deterioration such as would occur if the same stresses and strains were distributed geometrically similarly over a larger volume. Several well known physical features of plastic deformation give reasons for expecting such a dependence of the structural changes upon the size of the region over which the deformation extends. Now, fatigue is due to two manifestations of the progressive structural damage. First, this leads to strain hardening and thus to an increase of the local stress amplitude during cyclic straining, as seen in Figs. 4, 5, 6, etc. Second, it gradually weakens the cohesion (the fracture stress); it may even reduce it to zero, as in the case of fatigue crack formation in the slip plane without substantial help from normal stresses. If, therefore, the progress of structural damage depends on the size of the deformed region, small volumes of stress concentration may have an inherently higher fatigue endurance than the material in bulk.

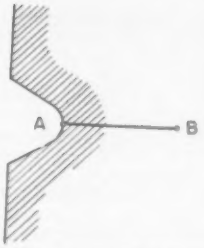

Fig. 13 Crack (AB) developing at the root of a notch

A third, more trivial, possibility of a size effect is indicated in Fig. 13. Here, AB represents a crack extending from the bottom of a notch. Suppose that the elastic stress concentration factor of the notch alone is q; in the absence of the crack therefore, the stress at A would be q times higher than the stress σ at large around the notch. However, the stress that determines the possibility of propagation of the crack AB is the one at B, and this differs from $q\sigma$ in two respects. First, even without the crack the stress at B would be lower than at A; second, the crack upsets the stress concentration of the notch. Therefore, the effective stress concentration factor of the combination may be much less than the product of the individual factors for the notch and for the crack. This argument, of course, rests essentially on the assumption made in Fig. 13 that the crack cannot be considered as small compared with the notch. If it can, it is in a stress field raised by the factor q, and the maximum stress at the edge of the crack is then obtained by multiplying σ with the product of the individual stress concentration factors of crack and notch. This is the reason why a familiar argument to explain the notch insensitivity of cast iron is insufficient. It consists in the remark that this material contains so many cracks (graphite flakes) that any additional stress concentration cannot matter. However, if the notch is on a larger scale than the graphite flakes (as is usually the case), the resulting stress concentration factor is obtained not by addition but by multiplication of the individual factors for the notch and for the flake, and then there is no reason to expect any abnormally low notch sensitivity.

The circumstance that the surprisingly low notch sensitivity of materials in all probability is a size effect shows that one must not rely on it in the design of structures in which the volumes of the stress peaks are relatively large. In notch fatigue tests, the root radius of the notch in rotating beam specimens is usually of the order of 0.05 to 0.5 mm.; the volumes of the stress peaks in welded structures or pressure containers are of a higher order of magnitude, and it would be unjustified to assume that they are no more dangerous than the regions of high stress in notched specimens for rotating beam tests. Unless evidence to the contrary is presented, therefore, one has to disregard the results of the usual notch-fatigue tests in assessing the danger of more large-scale stress peaks in engineering structures.

In view of the great practical importance of the matter, it would be very desirable to carry out notch-fatigue experiments with geometrically similar notched specimens spread over a wide dimensional range under strictly controlled metallurgical and surface conditions. Only such experiments can cast light upon the physical nature of the phenomenon of notch insensitivity and provide a sound basis for design.

9. FATIGUE AT HIGH STRESS AMPLITUDES

It was remarked already that pressure vessels are hardly ever subjected to millions of load cycles; often, as in the case of boilers, the number of load repetitions during their lifetime does not exceed a few thousands. It is of interest, therefore, to investigate how the number N of cycles to fracture decreases with increasing stress range S or strain range ϵ.

The answer is known for stress ranges not far above the endurance limit: it is given by the approximately straight inclined part of the log S–log N curve (Fig. 14). The approximate straight-line relationship between log S and log N in the nearly elastic range above the endurance limits is not only a well-established experimental fact; it also follows from the theory sketched in Section 7, with a few simple assumptions about the shape of the stress-strain curve, etc.

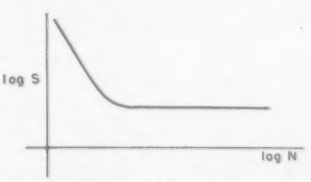

Fig. 14 Typical log S–log N curve of a ferrous material

So long as the bulk of the specimen is approximately elastic, it does not make any difference whether it is the logarithm of the stress range or of the strain range that is plotted as a function of log N; since S and ϵ are proportional, the curves obtained are identical, and cycles of constant stress amplitude are at the same time cycles of constant strain amplitude. Outside the range of approximate elasticity, however, the question arises: Should one expect any straight-line relationship similar to that in nearly elastic ranges? And if there is one, will it exist between

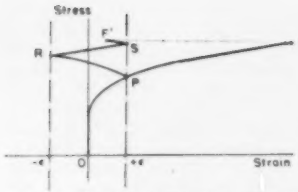

Fig. 15 Strain hardening material under cycles of constant plastic strain amplitude

log S and log N for cycles of constant stress amplitude, or between log ϵ and log N for cycles of constant strain amplitude?

A plausible answer can be obtained easily in the limiting case where the plastic strain amplitude is constant and so large that the elastic strains are comparatively negligible. Let Fig. 15 refer to alternating straining of this type, OA and OB being the maximum and minimum values of the strain, and OPF a schematic cyclic stress-strain relationship in which the Bauschinger effect has already been taken into account. The rise of the yield stress with cyclic straining is represented by the zig-zag curve $OPRS$ . . .; obviously, Fig. 15 is a special case of Fig. 4 in which the strain limit lines AX and BX are vertical because the elastic deformations are negligible on the small scale of the abscissa required by the large plastic strains to be accommodated. As before, let it be assumed that fracture occurs when a critical value of the yield stress, or, what amounts to the same, a critical value of the total absolute plastic strain is reached. Suppose the number of cycles to fracture, i.e., the number of zig-zags to the fracture point F', is N_1 for a strain amplitude ϵ_1. If the strain amplitude is q times less, the number of zig-zags to fracture is approximately q times larger;* in other words, ϵN = const., or

$$\log \epsilon + \log N = \text{const.} \qquad (1)$$

This is the equation of an inclined straight line in the log ϵ–log N plot. Consequently, we may expect the log ϵ–log N relationship to be approximately linear not only in the familiar limiting case of negligible plastic strains, but also in the opposite case of large plastic and negligible strains at constant strain amplitude, provided that a few rather plausible simplified assumptions about the shape of the stress-strain curve and the criterion of fracture are justified.

This consideration receives confirmation from an experimental investigation carried out by Tör, Ruzek and Stout[4] for the Pressure Vessel Research Committee of the Welding Research Council. Steel strips of $^5/_8$ in. thickness were subjected to alternating bending at constant maximum strains in the top and bottom surface; the strain values were 0.15, 0.4, 0.7 and 1.0%. Two slightly different low-carbon steels were used, with very similar results. Although the scatter was considerable, the average number of the cycles to fracture for various preliminary treatments of the specimens satisfied the linear relationship eq. (1) very well.

In most practical problems, the strain amplitude is not constant; it may vary in the course of the cyclic loading, for instance, according to the zig-zag curves in Figs. 4, 5, or 6. Even in such cases, the number of load cycles to fracture can be calculated easily if the assumption used for deriving Equation 1, that of a critical value of the total absolute strain at fracture, is correct. With this criterion, fracture occurs when the zig-zag curve reaches the height of the critical point F on the stress-strain curve for cyclic loading, and the number of the preceding zig-zags is N. If F is above the apex Z (in Fig. 4, X) of the strain limit lines, it cannot be reached by the zig-zag curve, and the strain range would seem to be a safe one. How is this compatible with the fact that, as soon as the cycle involves appreciable plastic deformation, the range is not safe and fatigue failure is bound to occur? The solution of the apparent contradiction is that Fig. 15 and the attached consideration refer to macroscopic (bulk) strains only which alone are important at very large strain amplitudes. At small amplitudes, the bulk of the specimen is, or soon becomes, purely elastic and past the danger of fracture. However, in every real material there are microscopically small regions of local stress concentration, or local softness, and the condition of a safe range may not be fulfilled at these points. Consequently, at these points cracks arise which then spread and lead to the fracture of the specimen. In extreme cases, the progressive deterioration during cyclic loading may be confined to the closest neighborhood of one or two fatigue cracks originating at points of local weakness, and the bulk of the specimen may reveal no sign of the approaching failure. This is the cause of the failure of many attempts to recognize whether a stress range is safe or unsafe before fracture or at least observable cracking has occurred, e.g., from X-ray photographs, hysteresis measurements or other methods. Sometimes one of these fatigue-diagnostic methods works fairly well for a given material, but fails with a slightly different one.

Part III

10. PRACTICAL CONSIDERATIONS

The preceding consideration gives fairly definite hints about the probable influence of several factors upon the fatigue behavior of pressure vessels.

The first point that stands out is a negative one. While plastic yielding is a valuable factor in reducing the higher local stress peaks in single loading, it cannot reduce the local stress amplitude that finally develops at the stress peaks after a large number of load cycles (unless the stress-strain curve for cyclic loading becomes asymptotically horizontal). All that local yielding can do is to reduce the mean stress of the cycle which becomes zero if the apex of the strain limit lines is above the plastic stress-strain curve (cf. Figs. 3 to 6). In this case, however, the maximum stress of the cycles is always equal to the current value of the elastic limit acquired by strain hardening during cyclic loading; it is, therefore, higher than the initial elastic limit of the material. This implies in general that the stress cycle is not safe for any number of load cycles, and ought to lead to fracture after a sufficient number of load repetitions unless the size effect saves the situation (cf. Sect. 8).

Since considerable plastic deformation must have been the rule rather than the exception in boilers constructed of plain carbon steels in the past, the question can be asked whether the comparative rarity of genuine fatigue failures was due only to the small number of load cycles applied during the useful life of the boiler or also to other factors. Two such factors seem to have been considered in the literature: first, the occurrence of strain aging at the plastically deformed stress peaks; second, local strain hardening and the consequent rise of the elastic limit at the stress peaks during the water pressure test. In the following, these two factors should be discussed briefly.

11. LOCAL STRAIN HARDENING DURING THE PRESSURE TEST

In pressure vessels made of low-carbon steel, strain hardening can hardly be an important factor. After the upper yield point has been exceeded, the yield stress remains at the level of the lower yield point during the entire process of yielding which usually extends over a strain range of several per cent. Since strains of this magnitude are unlikely to occur even at point of high stress concentration, it seems that the effect of local strain hardening can be disregarded in materials that show a distinct lower yield point.

On the other hand, the initial part of the stress-strain curve of alloy steels not showing the yield phenomenon rises steeply, and the possible influence of strain hardening upon fatigue endurance deserves here closer consideration. Let AX in Fig. 16 be the strain limit line corresponding to the working pressure of the vessel, BY that for the water pressure test, and OW that for the pressure zero. If the stress-strain curve lies below the

* The number of zig-zags would be exactly q times larger for a stress-strain curve consisting of an initial vertical part followed by a straight sloping part.

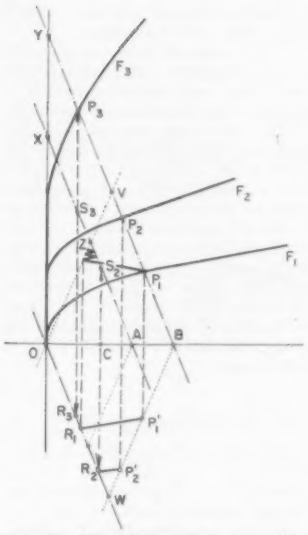

Fig. 16 The effect of a preceding pressure test upon the variation of stress and strain at a plastic stress peak under repeated load; no Bauschinger effect

point of intersection Z of the strain limit line AX and of the corresponding auxiliary line OZ (which is the folded strain limit line OW), the pressure test leads to the point P_1, and the subsequent release of the pressure to P_1' and R_1. Subsequent applications of the working pressure cause the stress strain point in the folded diagram to ascend along the zig-zag shown in the figure toward the apex Z, so that the prestressing by the water pressure test does not alter the local fatigue process significantly.

Consider now the case represented by the higher stress-strain curve OP_2F_2. The release of the pressure after the water test leads to the point R_2, and the elastic limit CR_2 at this point is higher than the stress CS_2 produced by the subsequent application of the working pressure. In the absence of mechanical hysteresis and Bauschinger effect, therefore, the plastic strain would "shake down" to a final value during the pressure test; the following repetitions of the working pressure, however, would always raise the stress to the previously acquired elastic limit. For many materials, such cycles would be unsafe.

Suppose, finally, that the stress-strain curve lies above both apices Z and V (the initial elastic limit, of course, can lie below either or both of these points). The release of the test pressure is then not followed by reverse plastic deformation, and the stress drops from P_3 to R_2 along a vertical, purely elastic, path. Application of the working pressure raises the stress to S_3, and its release makes the stress drop back to R_3. Repetitions of the working pressure, therefore, not only do not cause further plastic deformation, but the stresses reached remain below the elastic limit raised by the pressure test.

What are the practical conclusions from Fig. 16?

Without pressure test, the stress amplitude at the stress peak increases during repeated loading and converges toward the ordinate of the apex Z if the stress-strain curve is below Z (curve OP_1F_1 in Fig. 16); at the same time, the mean stress of the cycle tends toward zero. If the stress-strain curve is above Z (curves OP_2F_2 and OP_3F_3), no further plastic deformation occurs after the first cycle; the local stress amplitude is constant and equal to the final stress amplitude in the preceding case, which is one-half of the vertical distance OX between the lines OW and AX. The mean stress, however, is now above zero.

With a preceding pressure test represented by the strain limit line BY, the final local stress amplitude is still the same as before, for any position of the stress-strain curve. If the latter is below the limiting position in which the curve returning from P_1 goes through Z, the final mean stress is zero. It is seen easily from the figure that the mean stress is reduced by the pressure test if the stress-strain curve is above this limiting position. Of particular interest is the case where the zig-zag line returning from the point P_1 (i.e., the line interrupted by the letter S_2 in Fig. 16) intersects the line OV in a point whose abscissa is greater than OA. Repetitions of the working pressure cause then the local stress to oscillate between the lines XA and OW on a vertical that is to the right of the point A, so that the stress is always compressive. This occurs also if the stress-strain curve intersects the line YB in a point that is above V and whose abscissa is greater than OA; such a case, however, is of minor interest because it corresponds to a local stress peak so low that plastic yielding would not occur under the working stress alone (provided that the stress-strain curve is concave when seen from below).

It was mentioned repeatedly that the fatigue endurance does not seem to depend strongly on the mean stress until this approaches about one-half of the elastic limit. There are indications, however, that it begins to rise rapidly if the mean stress is negative (compressive) and approaching the amount of the stress amplitude; in other words, when tensile stresses disappear from the cycle. Although fatigue fracture seems to start usually along a slip plane on which excessive shear has taken place, it cannot spread easily if the walls of the crack are pressed together by a compressive stress; the importance of tensile stresses for fatigue fracture has been particularly emphasized by Almén.[7] It is to be expected, then, that the pressure test can increase the fatigue endurance of a local stress peak if the above condition of a fully compressive stress cycle is fulfilled i.e., if the first zig-zag returning from the point P_1 in Fig. 16 intersects the strain limit line OV in a point whose abscissa is greater than OA. The practical possibility of such an improvement has been demonstrated by Forrest[8] who could increase the fatigue endurance of notched duralumin specimens by about 100% by preloading in tension.

It might be dangerous to rely on the beneficial influence of the pressure test uncritically. The test can hardly increase the fatigue endurance significantly unless the above condition of an all-compressive stress cycle is at least approached; this, however, requires a very special relationship between the positions of the stress-strain curve and of the strain limit lines for the working pressure and for the test pressure. In addition, it is not known whether the effect observed by Forrest would be equally marked for stress concentrations extending over larger volumes. Finally, one must keep in mind that the pressure test may produce small cracks at points of high stress concentration; thus, it may conceivably lead to fatigue failure when the vessel would be safe without the test.

12. THE EFFECT OF STRAIN AGING

As mentioned, strain aging which occurs in low-carbon steels with a sharp yield may be of importance in increasing the fatigue endurance at stress peaks. The conditions under which such a beneficial effect may occur can be discussed with reference to Fig. 17 which differs from Fig. 6 only by the stress-strain curve being that of a steel with an upper and a lower yield point; the case is that of repeated bending of a mainly elastic bar, or plate, and the figure refers to the thin plastic surface layers of the plate. At the first loading, the upper yield point is exceeded and the stress-strain point P, on the strain limit line AX reached. When the load is removed, the stress-strain point would follow the path $PP'R$ in the absence of Bauschinger effect; in reality, it takes the curved path PR''. The second loading would lead to a point on the stress-strain curve if it took place immediately; however, strain aging will be practically complete before the second pressure load is applied to the boiler, and it will have raised the yield stress to the value of the new upper yield point U. If this happens to be above the strain limit line AX, no further plastic deformation can take place: the plastic strain is "shaken down" to its final value by strain aging after the first cycle. Whether this process occurs depends on the relative position of the strain limit lines

and the stress-strain curve, and on the difference between the upper and lower yield points. The upper yield point is a rather capricious quantity; stress peaks may easily make it disappear, i.e., they may depress it to the level of the lower yield point. On the other hand, if the stress distribution is extremely uniform, the upper yield point may rise 100% above the lower yield point. Since nonuniformities of stress distribution are fairly effectively eliminated by plastic yielding before the strain-aging process, the point U may easily be very high above P, and the chances of a "shakedown" by strain aging are good.

A comparison of Fig. 17 with Fig. 16 indicates that strain aging may be more effective than the strain hardening during prestraining in improving fatigue endurance. This possibility will have to be remembered whenever low-carbon steels are replaced by stronger alloy steels that do not show the yield phenomenon.

Strain aging, of course, does not occur at sufficiently low temperatures. However, steels that show substantial strain-aging cannot be used in any case under such circumstances because they become notch-brittle at temperatures not far below, and sometimes above, the freezing point of water.[8, 9] This excludes their use of the construction of pressure vessels below a temperature that must lie above the transition temperature of the steel, separated from it by a generous safety margin.

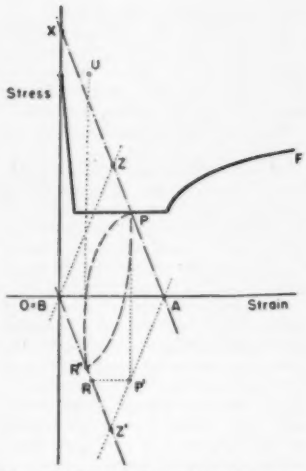

Fig. 17 Effect of strain aging upon the local stress amplitude at a plastic stress peak

Summary

1. A graphical method is given for obtaining the stress and strain amplitudes and their change during cyclic loading at local stress peaks exceeding the elastic limit.

2. Unless strain hardening is absent, the yield stress is bound to rise at the points of local yielding during cyclic loading until plastic deformation ceases. When it has ceased, the stress amplitude is the same as it would have been in the absence of yielding. Since the influence of the mean stress of the cycle upon the safe amplitude in the interval between alternating and repeated stressing is usually a minor one, local plastic yielding does not generally reduce the danger of fatigue failure.

3. The relatively small notch-sensitivity in fatigue tests, in all probability, is a size effect. It would be dangerous to rely on empirical stress concentration factors obtained from notched bar fatigue tests in assessing the danger of fatigue in very much more extended stress concentrations in engineering structures.

4. If the assumption is made that fracture in alternating straining at high strain amplitudes occurs when the total absolute amount of the plastic strain reaches a critical value, the number of cycles to fracture must be approximately inversely proportional to the strain amplitude. This is in agreement with observations.

5. In low-carbon steels that show the yield phenomenon and develop Lüders lines, strain hardening by prestressing is unlikely to increase the fatigue endurance.

6 In steels that show no yield phenomenon but have a steeply rising stress-strain curve, as well as in typical nonferrous metals, the effect of prestressing upon the fatigue behavior of the structure is probably usually insignificant; it may be beneficial if the residual stress left after pre-stressing is so strongly compressive that the stress remains compressive throughout the working cycle, and it may be injurious if the pre-stressing has led to the formation of microscopic cracks at a stress peak.

ACKNOWLEDGMENT

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Hydrogen in Mild-Steel Weld Metal

Review of published and unpublished information on the occurrence and effects of hydrogen in mild steel weld deposits made by shielded-metal-arc welding with covered electrodes, hydrogen in commercial electrodes, effects of hydrogen on porosity, cracking, fisheyes, mechanical properties, welding considerations, practical applications and engineering recommendations

by A. L. Schaeffler, H. C. Campbell and H. Thielsch

Summary

Definition

Hydrogen embrittlement is a term applied to the reduction in the ductility and toughness of steels which is caused by presence of small quantities of hydrogen.

Hydrogen in Weldments

Hydrogen is generally supplied to the weld metal from either (1) certain atmospheres which may surround the welding medium and/or the presence of humidity, or (2) an electrode coating containing moisture, cellulose or other hydrogen producing compounds or (3) the base metal itself.

Mechanism of Embrittlement

It is generally believed that hydrogen, which is evolved from substances in the electrode coating, is dissociated into atomic hydrogen by the intense heat of the arc atmosphere. In this state, hydrogen is readily soluble in iron and thus diffuses into the molten weld metal from the arc atmosphere. The diffusion rates of atomic hydrogen are higher in ferrite than in austenite and depend also upon the permeability characteristics of each particular steel. In the absence of phase changes, the diffusion rates tend to increase with temperature. However, they are noticeable even at ordinary room temperature. When the atomic hydrogen enters porosity, cavities, microcracks, etc., which, although often extremely small, are present in cast steels and weld deposits, it tends to change into the molecular form. In this state, hydrogen does not diffuse because of the larger size of the molecule and thus it remains in the steel. This so-called precipitation of molecular hydrogen is believed to cause severe multiaxial stresses.

If the stress system permits ductility, the steel can withstand these severe internal stress concentrations. However, if the steel is hard and brittle or if the stress system does not permit plastic deformation, failure may occur, particularly if a high degree of restraint has introduced severe shrinkage stresses. Thus the degree of embrittlement is a function of the amount and nature of the hydrogen present and the magnitude, distribution and nature of the internal stresses in the weldment.

Appearance of Fractures

The fractured surface of slowly deformed specimens, when embrittled by hydrogen, will usually exhibit bright spots which are usually identified as "fisheyes." The center of the bright spot generally contains a dark appearing crack or porosity.

Effects on Mechanical Properties

The effects of hydrogen on mechanical properties may be ascribed to one or several factors: (1) void spaces, cavities or microcracks, (2) the internal state of stress and (3) the rate of straining. The first two have already been mentioned. Straining tends to increase susceptibility to hydrogen embrittlement. This is believed to be due to the fact that straining provides areas within the steel in which molecular hydrogen can form. However, at very high strain rates, the hydrogen does not have sufficient time to diffuse and form the molecular state. Under these conditions, strain rates approaching impact-testing rates would not increase the embrittlement of weldments of relatively high-hydrogen content. However, the straining rates which occur in tensile and bend tests increase the severity of the hydrogen embrittlement. Other factors and mechanisms may somewhat obscure these results.

Welding Considerations

In most ordinary welding operations, the use of the special low-hydrogen electrodes may not be necessary. However, when hardenable steels are to be welded or when shrinkage or other factors set up severe multiaxial residual stresses, the use of low-hydrogen electrodes may be advisable or even essential.

INTRODUCTION

IN RECENT years considerable attention has been given to studies of the effects of hydrogen on the physical properties of steels. When hydrogen is present in wrought and cast steels, it generally occurs in such small amounts that it does not affect the mechanical properties significantly. However, it

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has been observed that the presence of quantities of hydrogen as small as 0.0003 weight per cent causes a reduction in the ductility and toughness of the steel. This loss in ductility and toughness is considered "abnormal" since it is not accompanied by an increase in tensile strength or hardness. Moreover, the effect generally is only temporary because aging for a sufficient period of time at a moderate, or even at room temperature, tends to remove all but insignificant amounts of hydrogen.

The embrittlement which is associated with the loss of ductility and toughness is termed *hydrogen embrittlement.*

Welding with bare electrode rods or wires is ordinarily not desirable because, during the transfer of metal from the electrode to the base metal, the liquid weld metal tends to absorb oxygen and nitrogen from the atmosphere. This generally produces a very brittle weld deposit. To prevent this detrimental absorption of oxygen and nitrogen, protective gases have to be provided which shield the weld metal so that it is transferred without contact with the ordinary atmosphere. This can be accomplished either by surrounding the liquid weld metal with a gas stream that is not absorbed by, or at least does not embrittle, the weld metal or by covering the electrode with a mineral and/or organic coating which produces protective gases and slags during the welding process.[7, 8]

In weld deposits made from coated arc-welding electrodes, significant quantities of hydrogen are generally introduced from the electrode coating into the weld metal. Even weld deposits from lime-ferritic or basic* electrodes, which are considered to be low-hydrogen types, may thus contain 10 to 20 times as much hydrogen as ordinary wrought steels.[2, 14] In fact, some weld deposits from high-silicon-bearing electrodes have been found to contain 30 times as much hydrogen as ordinary steels.[4] Because hydrogen, in these larger quantities, may be detrimental to the physical properties, numerous efforts are being made to develop special low-hydrogen types of electrodes and to prevent moisture absorption by the electrode coating.

The low-hydrogen electrodes have also been referred to as cellulose-free, low-moisture, mineral-coated, lime-coated[2] and lime-ferritic types.[2, 5, 6] Probably the term lime-ferritic is most descriptive because the term denotes both the type of coating and the type of core wire, that is, a lime-base, low-hydrogen type coating on a mild-steel or low-alloy (ferritic) type core wire.

* European usage.[12]

COVERED ELECTRODES

The primary purposes of the coatings on covered electrodes are (1) to prevent or minimize the absorption of atmospheric oxygen and nitrogen by the liquid weld metal by providing a gas shield against the atmosphere and (2) to facilitate weld-metal alloying and deoxidation.

Table 1 lists typical results which show how oxygen and nitrogen in the weld metal produced by bare and covered electrodes affect the mechanical properties of an all-weld-metal specimen.[20] These results show that the covered electrodes, which produce slags and protective gases, provide protection for the molten metal during deposition and thus help to produce a weld deposit which will generally exhibit satisfactory mechanical properties. The actual shielding action depends upon the type and thickness of the coating.

Electrode coatings usually contain materials such as organic compounds, oxides, hydroxides, carbonates, carbonyls, silicates, chlorides, fluorides and various other metallic compounds.[21, 27, 31, 32]

The first commercial coatings produced in the United States were mainly composed of cellulose and sodium silicate. During welding, these substances were primarily decomposed into CO, H_2 and small amounts of CO_2 and water vapor.[2, 20]

Actually, the atmospheres produced by all covered commercial electrodes contained different amounts of these four gases. The reaction, which takes place at about 2370 to 2730° F. (1500 to 1800° C.) may be described[19, 33, 39] by the equilibrium relation generally called the water-gas reaction.

$$CO + H_2O \rightleftarrows CO_2 + H_2$$

The operating characteristics of the commercial mild-steel and low-alloy-steel electrodes, which primarily depend upon the type of electrode coating, are listed in Table 2.

Table 3 gives the gas content of typical shielding atmospheres produced by various electrodes which are manufactured commercially in the United States. The constancy of the equilibrium "constant" or mass-action factor "Kw" indicates that approximate equilibrium conditions are obtained in the arc.[19]

The effect of moisture in the electrode coating will vary with the type of coating. Thus moisture, when it is present in the low-hydrogen, lime-ferritic types of electrodes, is normally accepted as being detrimental. On the other hand, in cellulosic-type coatings a moderate moisture content is held to be beneficial. The generally accepted explanation is that moisture in

Table 1—Effects of Oxygen and Nitrogen on the Mechanical Properties of Weld Metal[20]

	Composition, %*		*Yield strength,*	*Tensile strength,*	*Elongation*	*Charpy*	*Bend*
	O	N_2	*psi*	*psi.*	*% in 2 in.*	*ft.-lb.*	*elongation %*
Bare wire	0.227	0.150	25,000–40,000	25,000–45,000	2.0	1.0–2.0	3
Covered electrodes (cellulose-type coating)	0.0448	0.0067	45,000†	57,000†	35	35.0	Over 30

* Different types of electrode coatings will produce variations in the composition of the weld deposit—particularly in the nitrogen content.

† Somewhat higher values could be expected from present-day electrodes.

Table 2—Operating Characteristics of Mild-Steel and Low-Alloy-Steel Electrodes*[20, 146]

Classification	Current and polarity	Welding positions	Type of covering	Penetration	Surface appearance	Slag
EXX10	d. c., reverse polarity (electrode positive)	All	High-cellulose sodium	Medium to deep	Flat, wavy	Thin
EXX11	a. c., or d. c., reverse polarity (electrode positive)	All	High-cellulose potassium	Medium to deep	Flat, wavy	Thin
EXX12	d. c., straight polarity (electrode negative) or a. c.	All	High-titania sodium	Medium	Convex, rippled	Heavy
EXX13	a. c. or d. c., straight polarity (electrode negative)	All	High-titania potassium	Shallow	Flat or concave, slight ripple	Medium
EXX15	d. c., reverse polarity (electrode positive)	All	Low-hydrogen sodium	Medium	Flat, wavy	Heavy
EXX16	a. c. or d. c., reverse polarity (electrode positive)	All	Low-hydrogen potassium	Medium	Flat, wavy	Heavy
EXX20	d. c., straight polarity (electrode negative) or a. c. for H-fillets; d. c., either polarity, or a. c. for flat position welding	H-Fillets and flat	High iron oxide	Deep	Flat or concave, smooth	Heavy
EXX30	d. c., either polarity, or a. c.	Flat only	High iron oxide	Deep	Flat, smooth	Heavy

* The two symbols XX in the electrode classification, for example EXX10, indicate the minimum tensile strength of the deposited weld metal in the stress-relieved condition. The last two numbers represent the type of coating. Thus an E7010 electrode will produce a weld deposit with a tensile strength of over 70,000 psi. and will have a high-cellulose, sodium-type coating. In the 60,000 psi. class (mild steel) the tensile test is made on an as-welded deposit. In the 70,000 psi. and higher classes (low alloy) the tensile test is made on stress-relieved deposits.

these coatings does not seem to increase the partial pressure of hydrogen. In fact, in a few cases the partial pressure of hydrogen has been found to decrease with increases in the moisture content of the cellulosic coating. This contention has been supported by theoretical considerations[23] and by observations that fisheyes which are associated with hydrogen embrittlement, decreased with increasing moisture content.[24] The presence of moisture has also been held to be desirable on the grounds that its dissociation in the flux crucible of the electrode controls the decomposition of the organic portion of the coating.[21]

In lime-coated electrodes, increases in the moisture content will raise the partial pressure of hydrogen and, in turn, increase susceptibility to hydrogen embrittlement.[27, 33, 35–37] The hydrogen content of mild-steel deposits as a function of the moisture content is given in Fig. 1 for several electrode grades.[27]

The effect of changes in the moisture content of the coating may not always be self-evident. Stout, Doan and co-workers[38] found that test welds in ship steel showed only a slight impairment in properties when a lime-ferritic electrode was soaked in water* or oil before welding or when city gas was introduced into the weld zone; and a cellulosic electrode† was baked at 1000° F. (540° C.) with no appreciable improvement in the properties of the deposited weldment. It seems likely that differences in performance could have been detected had their welds been made under higher restraint on a more hardenable steel. Thus Flanigan[25] found that soaking low-hydrogen E6016 electrodes in water or introducing hydrogen gas into the arc when welding with dry electrodes did not greatly affect the

Table 3—Mass-Action Constants for the Reaction Between Gases in Various Arc Atmospheres[19]

Name	Electrode type	Per cent by volume in arc atmosphere H_2O	H_2	CO	CO_2	Kw*
X1	E6010	16.2	40.7	39.4	2.7	0.172
X2	E6013	17.2	36.7	42.3	3.8	0.191
X3	E6020	20.6	41.4	34.2	3.8	0.223
X4	Experimental LHLC†	9.0	19.2	63.4	8.4	0.283
X5	Experimental LHLC†	10.4	16.9	61.3	11.4	0.304
X6	Experimental LHLC†	12.2	15.4	59.5	12.9	0.274
X7	Experimental LHLC†	17.4	10.7	49.9	22.0	0.272
X8	Experimental LHLC†	8.2	7.5	68.4	15.9	0.213
X9	Experimental LHLC†	8.1	10.6	68.6	12.7	0.242
X10	Commercial LHLC†	8.1	8.7	69.0	14.2	0.221
X11	Commercial LHLC†	2.1	2.1	77.1	18.7	0.242
X12	Experimental LHLC†	1.5	1.8	79.8	16.9	0.254
					Av.	0.241
Larson's data, cellulose-sodium silicate coating		5.6	51.2	42.1	1.1	0.239

* Mass-action constant for water-gas reaction:

$$Kw = \frac{P_{H_2} \times P_{CO_2}}{P_{H_2O} \times P_{CO}}$$

† Low-hydrogen, lime-coated.

* Actually, soaking in water is not necessarily the most effective method of introducing moisture into the arc atmosphere. Thus, Winterton[147] has found that five times as much hydrogen evolved from a weld deposit made with a lime-ferritic electrode exposed to damp conditions for a period of several weeks as from a weld deposit made from the same electrode after it had been immersed in water for a few days.

† Ordinarily a cellulosic electrode should not be baked at such high temperatures since some moisture in the coating is necessary for efficient operation of this electrode.[147] Baking at temperatures even as low as 230° F. (110° C.) tends to effect the performance adversely.[147] On the other hand, tests on electrodes equivalent to the EXX12, EXX13 and EXX15 types have shown that baking reduces the hydrogen content, and that this is usually associated with a decreased tendency toward underbead and weld-metal cracking.[147]

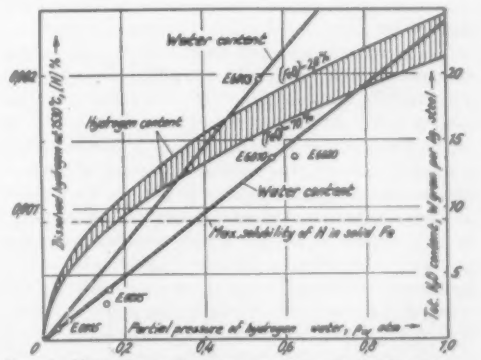

Fig. 1 Hydrogen solubility at 2785° F. (1530° C.) vs. partial pressure and moisture[27]

ductility if the cooling rates below about 400° F. (205° C.) were not too rapid. More rapid cooling rates, however, can cause considerable impairment[35, 91] which might be associated with the formation of low-temperature transformation products coupled with hydrogen embrittlement.

Additions of $CaCO_3$ to cellulosic-, titania- and iron-oxide-type coatings supply CO_2 and would tend to increase the partial pressure of CO. On the other hand, in lime-type coatings, $CaCO_3$ additions would decrease the partial pressure of CO.[39] The effect of variations in the composition of experimental coatings is shown in Fig. 2.[2]

Any increase in CO_2 will always decrease the partial pressure of hydrogen by (1) dilution and (2) oxidation of hydrogen to water vapor in agreement with the basic equilibrium equation.

The ability of a metal system to absorb hydrogen has been related to a so-called *hydrogen potential* which is a chemical attribute of the hydrogen released during the moment of reaction which generates known or calculable pressures of hydrogen.[47, 180] Since the absorption of hydrogen in metals is a function of the hydrogen pressure, these hydrogen potentials provide a basis for calculating the liability of the various metal systems to hydrogen pickup from the moisture reaction.[47, 180]

Weld defects from moisture in electrode coatings can be more severe than those resulting from an atmosphere of atomic hydrogen.[152] Moreover, air, even when relatively dry, may hydrogenize steel as effectively as melting under one atmosphere of pure H_2.[152] Increasing humidity increases the hydrogenizing power of the air to an equivalent of many atmospheres of pressure of pure H_2.[47] The gas content of the metal will influence this condition. The lower the *effective oxygen* pressure of the metal, the greater will be the hydrogen potential.[47] *Effective oxygen* is the oxygen which can be easily removed from the original chemical compound.[153] In metal-arc welding the effective oxygen refers to the oxygen obtained by the reduction of those oxides which have a sufficiently low heat of formation to allow their decomposition by the bead produced by the welding arc. Iron oxides, nickel oxide and water (hydrogen oxide) are typical oxides readily reduced by the welding heat.

The presence of a certain amount of effective oxygen seems to be important to the deposition of good welds. For example, in the cellulose type of coatings it is common practice to balance the formula with a certain amount of moisture in the coating.[141] If these coatings are baked too dry, the weld is very likely to contain pits and holes especially along the edge of the weld.[141] If these are not removed by chipping, they often result in weld defects which are readily observed in radiographs.[141] According to Larson[141] this difficulty can be prevented by rehumidifying or, in some cases, by immersing the electrodes in water for a few minutes. However, porosity occurs also in the weld if the coating absorbs too much moisture—as in storage in a damp place.[141] Although such welds may appear perfect on the surface, radiographs would reveal porosity in the weld deposits .[141] This difficulty can be overcome by redrying the electrodes.[141] This illustrates that the presence of some water in the cellulose-type coatings is beneficial in that it provides a certain amount of effective oxygen. The hydrogen which is produced by the reduction of a moderate amount of water does not seem to be detrimental under ordinary welding conditions; that is, in welds of low restraint on a relatively low-hardenability base steel. However, beyond a certain limit of water the detrimental effects of hydrogen produced in the water reduction by the arc will outweigh the advantages of the effective oxygen—and porosity will result.

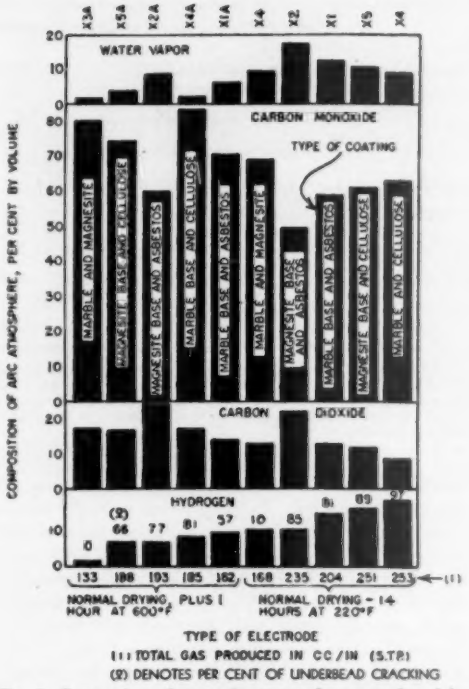

Fig. 2 Proportion of gases in atmospheres produced by experimental lime- and magnesite-coated electrodes[2]

Steel at 2910° F. (1560° C.), containing 0.01 weight per cent of FeO, for example, could become quite immune to hydrogen pickup if the air were moderately dehumidified as would be natural in cold clear weather; but hot and humid summer weather could quickly extend the hydrogenizing potential for that same steel to 10 atmospheres.[47] With lower oxygen contents the sensitivity of the steel to atmospheric moisture is tremendously increased.[47]

Because of the great effect of FeO, it is highly important to consider the action of those elements which strongly reduce FeO.[47] For example, as the carbon content increases toward the tool steel and even into the cast-iron ranges, the hydrogen potentials climb into

the hundreds of atmospheres.[47] For any given carbon content the potentials rise rapidly with temperature.

Aluminum and silicon also cause a very large increase in the hydrogen potential. This is significant when considering the increased cold crack sensitivity of killed steels.[152] Silicon, for example, reduces the effective oxygen content and produces hydrogen by the following reaction.[155]

$$Si + 2H_2O = SiO_2 + 2H_2$$

COMMERCIAL ELECTRODES

General Considerations

The selection of the type of electrode, and in particular of the type of covering, primarily depends upon the type of steel that is to be welded and upon the properties that the welded section should exhibit.[21, 41, 42, 89, 181]

It is also important to realize that the welding characteristics of coated electrodes are largely controlled by the nature of the coatings. Thus when the same core wires are covered with different types of coatings, the resulting electrodes often exhibit widely different operating characteristics.[112]

Cellulosic-Type Electrodes

The cellulosic-type electrodes[89] usually contain over 25% cellulose in the electrode coating. The balance is generally made up of titanium dioxide, various types of magnesium or aluminum silicates, metallic deoxidizers such as ferromanganese and sodium silicate solids*. Instead of sodium silicate, potassium silicate may be used.† Since cellulose readily forms hydrogen, these electrodes are primarily used in welding the ordinary unalloyed mild steels which are less susceptible to hydrogen embrittlement than hardenable alloy steels. Typical applications include pressure vessels, ship building and construction of bridges and buildings, storage tanks and pipes.

The cellulosic-type electrodes usually provide globular metal transfer and fair arc stability.[112]

Titania-Type Electrodes

The high titania-type electrodes[89] have a coating containing rutile, siliceous material, cellulose, metallic deoxidizers such as ferromanganese and liquid silicate binders. Since both sodium silicate‡ and potassium silicate§ are used, the electrodes, therefore, are termed high-titania sodium‡ or high-titania potassium§ types.[40, 41]

It will be noted that this coating contains cellulose, although in a smaller quantity than the cellulosic type of electrode; the weld deposits are thus often subject to hydrogen embrittlement. (In England, the addition of cellulose to coatings of the high-titania type is not practiced.[147])

The source of rutile used for these electrodes has been reported to affect the tensile properties of the weld metal.[43] Sensitivities of this nature, that is, to local variations in the coating ingredients, are probably not peculiar to any class of electrode.

The titania-type electrodes are used largely for light sheet-metal work and for fast production work involving moderate penetration and poor fit-up.

These types of electrodes usually operate with a stable arc, although the fine globular weld metal transfer combined with a relatively short arc results in a rapidly cracking sound.[156]

Iron-Oxide Type Electrodes

The iron-oxide coating*,[89] is essentially an all-mineral covering, with a high percentage of iron oxide, manganese compound and silica, and with sodium silicate binder. The coverings of both the EXX20 and EXX30 electrodes contain less than 5% cellulose.[156] Electrodes that deposit welds with tensile strengths of 70,000 psi. and over contain alloying elements to provide the desired mechanical properties.[156]

This electrode type depends upon extensive slag coverage and extensive slag-metal reaction for deoxidation and protection of the weld metal. The volume of gas generated by the iron-oxide coatings is far less than that of the other electrode types, E6010 for example. Therefore, although there is no great volume of hydrogen present, such as is the case in the cellulosic grade, the partial pressure of hydrogen is nevertheless high because such moisture as is present in the electrode remains undiluted by other gases. The iron-oxide electrode is thus not to be considered a low-hydrogen type, although it may be an all-mineral coating. Weld deposits particularly on air-hardenable steels may be subject to hydrogen embrittlement. However, the high welding currents which are commonly used are conducive to sound welds for the most part.†

The iron-oxide electrodes are used for heavy production welding of all types limited to flat production or H-fillet welding. Applications include pressure vessels, heavy machine bases and structural parts. These electrodes generally provide a spray-type of metal transfer and exhibit good arc stability.[112]

Low-Hydrogen-Type Electrodes

The low-hydrogen electrode coating consists largely of minerals, of which a high percentage are gas-forming materials such as calcium, magnesium, sodium or potassium carbonates.[156]

* Electrode Classification A.W.S. EXX10; (Brit. class 1)
† Electrode Classification A.W.S. EXX11; (Brit. class 1)
‡ Electrode Classification A.W.S. EXX12; (Brit. class 2)
§ Electrode Classification A.W.S. EXX13; (Brit. class 3)

* Electrode Classifications A.W.S. EXX20, EXX30; (Brit. class 4)
† This point seems to be controversial. British experience with equivalent electrodes is that high-welding currents are liable to increase considerably the cracking tendencies.[147] Tests carried out at the British Welding Research Assn.[147] have also shown that the evolution of hydrogen at room temperature increases with increasing welding current. Whether this accounts for the increased cracking tendency has not yet been established.[147]

The d.c.‡ and a.c.-d.c.§ types have been classified as low-hydrogen-sodium‡ and low-hydrogen-potassium.§[40, 41]

These coatings are essentially[†] free from hydrogen because of the careful elimination of any hydrogen-bearing materials from the coating and because of special baking procedures which reduce the moisture content generally to less than 0.5%. In addition, the coatings provide a voluminous gas shield, which is generated by the decomposition of the carbonate ingredients and which dilutes whatever residual moisture does enter the arc atmosphere.

The operation and arc characteristics of the low-hydrogen electrodes are similar to those of stainless-steel electrodes.[178] A short arc must be maintained during welding in order to confine the arc atmosphere to the welding zone.

Low-hydrogen electrodes were initially developed with a tensile strength in the 60,000 to 70,000 psi. range to produce deposits of exceptionally clean but thoroughly deoxidized steel and capable of permitting the introduction of a wide variety of alloys.[156] Cellulose, combined-water compounds and reducible oxides were omitted because of their detrimental effects on weld quality, weld appearance and electrode usability.[156] These features of the low-hydrogen electrodes permitted the extension of metallic-arc welding to the fabrication of steels previously difficult to weld or completely unweldable.[156] Thus, these electrodes have been proved very useful on many high-strength, high-carbon alloy steels, on malleable iron, on spring steels, for welding the mild-steel side of clad plates, for welding steels which will subsequently be enameled, for welding all high-sulphur- or selenium-bearing steels, and proprietory low-alloy steels and silicon steels.

OPERATING CHARACTERISTICS OF ELECTRODES

The operating characteristics of the major electrode classifications produced in the United States are listed in Table 2.

Penetration values for these electrodes are shown in Table 4.[21] These data indicate that the lime-ferritic electrodes require the highest amperage for efficient operation.

Mathias and Bunk[21] compared the deposition rate, efficiency, spatter loss and burn-off rate of a lime-ferritic electrode with similar characteristics of an E6020 type. At the same amperage, lime-ferritic electrodes have lower deposition and burn-off rates, but the amount of spatter is much less and deposition efficiency is greater. A direct comparison of these electrodes at the same amperage is probably valid; however, it is not useful to the welder because, as Smith and Rinehart[31] pointed out, lime-ferritic electrodes are generally used at higher operating amperages than the other mild-steel types (see Table 4). Nevertheless, low-hydrogen electrodes, although capable of operating at high current values, are not always used at amperages in excess of those used with other mild steel electrodes.[156] EXX12, EXX20 and EXX30 electrodes are regularly used with excellent results at current values equal to or higher than those used for the low-hydrogen electrodes.[156]

Similar considerations apply when comparing the deposition and burn-off rates of lime-ferritic and austenitic stainless electrodes[27] since the lime-ferritic types, because of their characteristically higher operating currents, surpass the austenitic types in practice.

In discussing operation, Barnett[42] stated that spatter with the lime-ferritic electrode is less than with any other E60XX type. Excellent radiographic soundness is attainable with good technique.

EFFECTS OF HYDROGEN

General Considerations

It is now generally believed by most investigators[24] that the hydrogen, which is evolved from substances in the electrode coating, is dissociated into atomic hydrogen by the intense heat of the arc atmosphere. In this state, hydrogen is highly soluble in the molten weld metal and readily diffuses into the weld and base metals.

Spatter

The influence of hydrogen on the spattering of fused

‡ Electrode Classification A.W.S. EXX15; (Brit. class 6)
§ Electrode Classification A.W.S. EXX16.
† Some of the lime-ferritic electrodes now used for low-strength "non-cracking" work produce atmospheres with as much as 10% hydrogen by volume. However, the trend is toward higher baking temperatures and lower hydrogen content for all low-hydrogen electrode grades.

Table 4—Penetration of Fillet Welds Manually Deposited in the Flat Position on 3/8-In. Steel with 5/32-In. Electrodes[11]

AWS-ASTM classification no.	*Type of coating*	*Current and polarity*	*Amperes*	*Volts*	*Penetration, mm.*
E6010	High-cellulose sodium	d. c. reverse	160	26	2.0
E6011	High-cellulose potassium	a. c.	160	26	1.3
E6012	High-titania sodium	d. c. straight	170	22	1.2
E6013	High-titania potassium	a. c.	170	20	0.5
E6020	High iron oxide	d. c. straight	175	33	1.9
E6020	High iron oxide	d. c. reverse	175	33	2.3
NRC-2A	Low-hydrogen lime-coated	d. c. reverse	195	26	1.3
E12015*	Low-hydrogen lime-coated	d. c. reverse	160 195	23 23	2.2 2.9

* Reference 27.

metal during welding with coated electrodes was studied by Erokhin.[44] Theoretically and experimentally he found that spatter was induced by the presence of hydrogen in the weld metal. It may be that any gas, particularly hydrogen, initially dissolved in the molten weld metal, might bubble out and cause spatter.

The low spatter loss of the hydrogen-free electrodes has been mentioned previously.[21, 42] The reduced efficiency of low-hydrogen Ni-Mo-V electrodes at high currents is attributed to spatter loss,[27] but this is obviously not a hydrogen effect.

Formation of Porosity and Cavities During Solidification

The detrimental effects of hydrogen which has been absorbed by the weld deposit are often closely associated with the presence of porosity and cavities. These are believed by many investigators to be caused in most cases by the evolution of CO, H_2O, H_2S and/or H_2Se in the solidifying steel. Hydrogen may also cause porosity, although it is felt by many investigators that the presence of some other material, such as water vapor, is required to initiate the reaction.[100] This point, however, is controversial since by normal methods of analysis, the porous solidified weld metal generally will show a relatively low hydrogen content.[100] Once porosity has been formed, atomic hydrogen may enter readily into the void space by diffusion.

There are cases when hydrogen itself is believed to cause the formation of porosity. For example, Mallett[19] stated that some weld deposits, made from electrodes coated with cellulose-type coatings, contained dissolved hydrogen in excess of its solid solubility, which is 13.3 cc. per 100 gm. at the melting point of iron. He assumed, therefore, that hydrogen may cause porosity. Electrodes which have been wetted by immersion in water have also been found to produce porosity.[29, 118] However, the fact that porosity in a weld is produced by immersing an electrode in water is not in itself sufficient evidence to advance the opinion that hydrogen is a source of porosity. Since water contains oxygen as well as hydrogen, FeO is formed by the reaction of oxygen from the water and during welding the FeO in turn reacts with carbon in the deposit to form CO which may produce porosity.[156] An electrode is designed to give adequate deoxidation to prevent the formation of CO when used under normal conditions.[156] However, if the deoxidation balance designed into an electrode is upset by immersion in water, porosity is bound to result.[156] In the case of conventional electrodes, a combination of base steel and electrode metal may result in a degree of deoxidation in excess of that for which the electrode is designed, and immersion of the electrode in water will decrease rather than increase porosity.[156] Although it is well recognized that hydrogen is very detrimental for many applications of metallic arc welding, it should be equally well recognized that both oxygen and hydrogen resulting from the decomposition of water play important roles in the successful application of the conventional electrodes.[156]

In tests made under synthetic atmospheres of 50/50 CO and CO_2, Mallett[2] found that weld deposits did not show porosity.

The differences in opinion on the effects of hydrogen on the formation of porosity may well be explained by an analysis of the process of solidification. Thus Fast[104] showed that, when molten iron is cooled rapidly in a small crucible by radiation and convection, it solidifies first on the surface. Because of the sudden drop in solubility at the freezing point, the solidifying iron retains so little gas in solution that the liquid iron underneath becomes temporarily supersaturated with gas. Fast[104] observed that at a certain moment several places in the solidified surface were pushed upward as a result of a vigorous formation of gas bubbles in the liquid iron. Sometimes the pressures are of such a magnitude that the liquid breaks through the protruding crust and flows over the solid surface with a "boiling" phenomena. Under these conditions, porosity may not only exist underneath the surface, but holes may also be formed in the surface. When the molten iron is cooled more slowly, more time is available for the dissolved atoms to diffuse through the liquid and solid metal to the surface. Because of the rapid rate of diffusion of hydrogen at elevated temperatures and the slower rate of solidification, most of the hydrogen can escape from the supersaturated solution without the formation of large porosity underneath the initially solidified surface of the iron. From these observations, it should seem likely that, even in large steel ingots, hydrogen itself would not be responsible for the formation of porosity.

Different considerations hold true for the solidification of weld metal. Thus, Fast[45, 104] pointed out that the iron deposited in welding does not solidify inward. Instead, solidification begins at the interface between the parent metal and the shallow pool of the molten weld metal. Thus in the solidification of ordinary weld metal (already containing carbon in solution), CO, CO_2, H_2, H_2O and N_2 are generally released in the form of gas bubbles.[104] Under normal conditions, this liberation of gases from the metal takes place before the outer layer solidifies. The "latent" or equilibrium pressure of the gases in the metal is then still greater than one atmosphere, but the formation of gas nuclei is prevented because, regardless of the cooperation of the "active places" in the interface between the solid and the liquid metal, this requires an additional pressure (capillary pressure).[104] However, generally the necessary "latent" pressure is no longer present at the end of the solidification process when most of the gas has already escaped. Only if there is any hindrance to the formation of gas nuclei (1) through preferred adsorption of sulphur at the metal surface (poisoning),[104] (2) in consequence of increased external pressure or (3) through any other possible causes can the formation of gas bubbles at the beginning of the solidification be

suppressed. Hydrogen evolved from the solidifying weld metal (in the later stages of solidification), resulting from the very much greater supersaturation of hydrogen in the solid weld metal, may cause porosity in that part of the weld metal which is still liquid. Such a "delayed" evolution of gas may account for porosity in the weld. It particularly occurs in weld deposits from electrodes containing small amounts of sulphur.[46]

Herres[20] also contended that hydrogen does not ordinarily form bubbles, but may segregate and precipitate to produce void spaces in dendritic interstices during (rapid) solidification. He believed that porosity is initiated by one of the following reactions which suggest CO or H_2O as the sources of porosity:

$$FeO + 2H \rightleftarrows H_2O + Fe$$
$$FeO + C \rightleftarrows CO + Fe$$

Herres[20] also stated that a critical moisture content was required to produce porosity in weld deposits. His data are based on an experiment using three sets of lime-coated electrodes having varying moisture content. Radiographs are presented which show that, with an optimum moisture content, the weld does not contain porosity. His demonstration is not convincing, however, because the weld free from porosity was made with the highest amperage and lowest voltage, two conditions which tend to minimize porosity anyway. Herres' statement that a critical moisture content is required to eliminate porosity is at variance with the accepted understanding and the work of Mallett and Rieppel[2] (reported previously) who produced sound welds without the use of moisture.

It is generally known that porosity can be produced in welds deposited with cellulosic coatings on sulphur- or selenium-bearing steels.[20, 88] Welds on the same steels with lime-base electrodes were free from surface porosity. These results are illustrated in Fig. 3 where serious porosity resulted in E6012 weld deposits on a SAE-1112 sulphurized called rolled steel.[152] Sound weld metal was produced with a low-hydrogen E6016 electrode.[152] Although several investigators[20, 88] have suggested that the porosity is caused by either of the following reactions

$$H_2 + S \rightleftarrows H_2S$$
$$H_2 + Se \rightleftarrows H_2Se$$

it seems more likely that porosity is not formed by hydrogen sulphide, but that sulphur retards the formation of porosity in the molten weld metal toward the solidification stage when the gas bubbles cannot escape as readily as at higher temperatures where the molten weld metal is more fluid.[104, 171] Actually, further theoretical and experimental work is needed to provide a satisfactory explanation. In any case, there is general agreement that an increase in the sulphur content of welds made with EXX12, EXX20 and similar electrodes produces porosity, whereas, with the low-hydrogen EXX15 type of coatings porosity is far less likely to be present. Increasing the phosphorus content in any weld did not cause porosity.[66, 172, 173]

As Zapffe[47] suggested, hydrogen may also be a source of porosity in steel when the metal reacts with steam (e.g., moisture in the electrode coating). Under these conditions, hydrogen is produced under terrific pressure and the metal is forced to absorb great quantities of the hydrogen which is later released upon cooling. Porosity can then result if the gas cannot escape rapidly. Chromium intensifies the reaction with steam and this could possibly be the reason why chromium-bearing

Fig. 3 SAE-1112 sulphurized cold-rolled steel welded with (left) Type E6012 and (right) Type E6016 (low-hydrogen) electrodes[152]

steels are more susceptible to porosity.[47] However, it may also be suggested that chromium (as well as many other elements) may reduce the diffusion rates of hydrogen in the steel and thereby support the formation of gas porosity.

These various results suggest that hydrogen, as well as nitrogen, should be considered as an important source of porosity.[104] In addition, a bubble, if it has been formed by CO or H_2O, has a zero partial pressure for nitrogen and hydrogen and hence these gases will diffuse into the bubble rapidly. The uninterrupted diffusion of hydrogen and other gases into a bubble together with the progressive solidification of the steel explains the presence of elongated cavities (wormholes) in welds.

Until now the discussion on the formation and gas content of porosity has referred primarily to hydrogen and CO. This, however, may be an oversimplification in that the gas entrapped in the porosity may also contain significant quantities of methane.[157] Hydrogen decarburizes steel[48, 153] at high temperatures according to the reaction:

$$Fe_3C + 2H_2 \rightarrow CH_4 + 3Fe$$

If a weld deposit into which hydrogen has been introduced is cooled and subsequently reheated in a vacuum, hydrogen will be withdrawn.[157] Heating at progressively higher temperatures produces a flow of hydrogen at each new temperature, although flow had actually ceased at the low temperature.[157] This effect can be produced up to and above temperatures at which substantially all hydrogen should have been removed. This is entirely consistent with the behavior expected of methane or a methane-hydrogen mixture.[157]

At each temperature and pressure a fixed quantity of methane is in equilibrium with a fixed quantity of hydrogen. If the temperature is increased from T_1 to T_2, some of the entrapped hydrogen will be dissociated and the liberated atoms will diffuse into the steel.[157] Equilibrium will be upset and methane will decompose to produce hydrogen and restore equilibrium conditions.[157] Heating to T_3 will repeat this process, with a further supply of hydrogen by methane decomposition. Thus, the behavior of the mixture (or of methane alone) is entirely consistent with the steplike evolution of hydrogen on heating to progressively higher temperatures.[157]

Other factors affect the formation of porosity. High welding speeds, by increasing the rate of solidification, tend to trap gases.[49] High welding currents ordinarily minimize porosity formation.[49] However, in sulphur-bearing steels porosity tends to increase with higher current.[171] In mild steel weld metal, silicon between about 0.10 and 0.50% promotes porosity. On the other hand, a higher silicon content or the absence of silicon have been found to minimize the formation of porosity. Similarly manganese above about 1.0% and carbon above 0.4% minimize the formation of porosity.[49] These results point out that, aside from the presence of hydrogen and other gases, there are various other factors which may either cause or promote porosity. It must also be realized that although some elements may behave beneficially by reducing the formation of porosity, they may cause other detrimental effects as, for example, they may promote crack sensitivity.

The shrinkage of molten weld metal containing hydrogen is considerably higher than that of essentially hydrogen-free weld metal.[182] This is attributed to microporosity caused initially by hydrogen.[182] The subsequent escape of hydrogen and the surface tension result in contraction of the porosity which is apparent by the increase shrinkage of the molten weld metal.[182]

Cracking Mechanism

Even before hydrogen embrittlement had been associated with the formation of fisheyes it had been realized that hydrogen could produce stresses in steels which could cause or promote cracking and failure in the steel and in welds.[9, 12, 161, 162] In fact, it had already been known for a long time that hydrogen may not only be introduced into the molten steel or weld metal at elevated temperatures, but may also diffuse into the steel at ordinary room temperature (see for example, Cailletet[163]). Thus if an atomic-hydrogen layer is developed at room temperature on the steel surface, as occurs in electrolytic reactions,[12, 15, 47, 50, 115] the hydrogen probably will diffuse into the steel. Hydrogen diffusion data are usually based upon permeability data.[160] Although ordinarily diffusion rates of hydrogen through metals rise with temperature, permeability also varies with the method of introducing hydrogen.[160] Nascent hydrogen released at the liquid-metal interface, as in an electrolytic cell, may introduce large volumens of hydrogen into the metal and develop high stresses at the interface. Under such conditions a high permeability is developed.[164, 165] The permeability is also influenced by the history of the metal. Iron previously subjected to hydrogen penetration is more readily permeable on each subsequent exposure. The increase permeability of freshly pickled iron is an example of this effect.[160] The iron may be restored to the initial permeability by a conditioning heat treatment.[105, 167]

When the atomic hydrogen enters the extremely small porosities and cavities which are present in cast steels and weld deposits, it tends to change into the molecular form and thus remain in the steel, since molecular hydrogen does not diffuse because of its larger size. This *precipitation* of molecular hydrogen causes multiaxial stresses[24, 45] whose severity depend on the pressures that are developed.

If the stress system permits ductility, the steel can withstand these severe internal-stress concentrations. However, if the steel is hard and brittle or if the stress system does not permit plastic deformation, failure may occur, particularly if a high degree of restraint has introduced severe shrinkage stresses.[20, 24, 51] In other words, the degree of embrittlement is a function

(a) (b) (c)

Fig. 4 Fisheyes in tensile fractures of all-weld-metal specimens. (a) Fisheyes originating at porosities; (b) fisheyes originating at coarse slag inclusions; (c) fisheyes originating at fine slag inclusions.[111] *Magnification 2 ×*

of the amount and nature of the hydrogen present, the magnitude, distribution and nature of the internal stresses in the weldment and the ability of the material to withstand these stresses. Thus as the severity of the internal stress system is increased, less hydrogen will be required to cause embrittlement.[22] These considerations explain why cold cracking which is due to hydrogen embrittlement is rarely found in mild-steel and austenitic plates, but is more common in low-alloy steels of high hardenability.

Even in the absence of microporosity and cavities, severe pressures which may exceed the cohesive strength of the weldment,[52, 117] may be developed by hydrogen in a steel. For example, in ferrite containing 6 cc. of hydrogen per 100 gm. of steel (0.00054 (wt. %) hydrogen) the equilibrium pressure at room temperature would amount to 2.2×10^9 psi.[52] Since such pressure far exceeds the tensile strength of the steel, internal cracks may be developed.[113] Under these conditions, even atomic hydrogen is believed[52–54, 121] to be capable of initiating fine cracks in hardenable steels—probably near dislocations or other lattice imperfections, or near disturbances which already exist in the steel.

Thus, when atomic hydrogen diffuses into a steel which does not contain discernible cavities, a considerable reduction in ductility can be observed, the severity of which depends upon the pressure of hydrogen in the steel, the internal state of stress and the rate of straining. These effects of atomic hydrogen ordinarily are only of a temporary nature since, in the atomic state, hydrogen readily leaves the steel at room temperature,[13, 28] until equilibrium is reached with the atmosphere.

However, the original ductility may never be entirely regained, probably because the submicroscopic cavities, rifts or dislocations, which are present in any ordinary material or which may have been caused by the atomic hydrogen, may retain some molecular hydrogen and hence cannot heal completely.

Appearance of Fractures

The fractured surface of a slowly deformed specimen such as a tensile test bar of an as-deposited weld which has been embrittled by hydrogen will usually exhibit bright spots similar to those shown in Fig. 4.[111] These are generally identified as "fisheyes." Their appearance in fractured welds is characterized by a central spot which may be an inclusion or may be a porosity, surrounded by a bright, embrittled area.[149] Both types are illustrated in Fig. 5. The walls of the porosity generally are very bright as shown in the enlargement in Fig. 6.[149] A larger gas porosity which is not surrounded by an embrittled area, can be seen also in Fig. 5.[149] Similar porosities, or wormholes, are illustrated more clearly in Fig. 7.[149]

Initially the appearance of fisheyes in the macrostructure of fractured surfaces was related to (1) the presence of microscopic particles of mechanically entrapped slag,[56, 122, 142] nonmetallic inclusions[56] and porosity,[143, 151] (2) a heterogeneous condition in the steel which leads to differential ductility[11] or (3) incipient microcracks developed during the drastic quenching undergone by the filler metal when deposited on cold (not preheated) base steel.[57, 95] As discussed in the previous paragraph, it is now generally accepted that the appearance of fisheyes can be related to the presence of inclusions of nonmetallic and slag particles and porosity. Moreover, fisheyes do not exist as a definite defect until the weld deposit is plastically deformed.[156] They are nondirectional.

In addition to "fisheyes," the fractured surface of a tensile specimen may exhibit microfissures (also called "flakes"). These microfissures are generally arranged in bands corresponding to the layer formation of the weld.[156] "Fisheyes," on the other hand, have a random orientation. Rarely, if ever, do microfissures appear as a bright area surrounding a slag inclusion or cavity.[156] Microfissures, unlike fisheyes, exist as definite defects in a weld and cannot be eliminated by heat treatment. When present, they tend to exist in a direction normal to the direction of maximum contractional stress.[156]

Helin,[122] Zapffe and Sims[13, 80, 120] and Duma[58] were actually the first to recognize that hydrogen was the real progenitor of fisheyes in weld metal. These observations were the natural consequence of earlier studies of Bennek, Schenck and Müller[128] and various other investigators[110, 129, 131, 132, 124, 139] who showed that the appearance of flakes and fisheyes in wrought steels could be related to the presence of hydrogen.

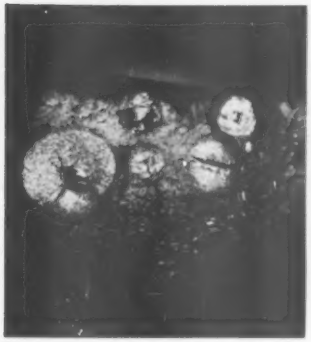

Fig. 5 "Fisheyes" in weld deposit fractured by bending.[149] *Magnification 10 ×*

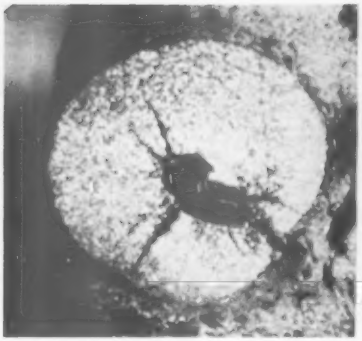

Fig. 6 Higher magnification of "fisheye" with center porosity shown in Fig. 5.[149] *Magnification 25 ×*

Fig. 7 "Wormholes" in weld deposit.[149] *Magnification 10 ×*

Fractures of these steels generally revealed coarsely crystalline spots which, subsequently, have been termed fisheyes.

Zapffe and Sims[12] particularly conducted many welding experiments to show that hydrogen was responsible for fisheyes and that hydrogen could produce embrittlement in steels. Tests were run to show that moisture in the atmosphere and moisture in the electrode coatings (cellulosic type) were the source of hydrogen. Since then, various other investigators[20, 55, 59, 60, 105, 111, 120, 135, 149] have studied the nature of the fisheyes in weld deposits. It has even been indicated that the size and number of fisheyes in E6012 electrode deposits seem to be independent of the source of an electrode-coating ingredient such as rutile, which does not contain hydrogen and therefore should bear no relation to the fisheyes.[43] On the other hand, it should be supposed that nonmetallic inclusions would vary in their ability to act as nuclei for the formation of fisheyes.[147]

METALLURGICAL EFFECTS OF HYDROGEN

Hydrogen, aside from promoting crack sensitivity, has also been suggested as a potent alloying element in steel as well as in cast iron.[17, 20, 61] As such, it delays the rate of the formation of high-temperature carbides and so promotes hardenability.

The solubility of hydrogen in pure alpha, gamma, delta and liquid iron has been studied by several investigators and summarized by Geller and Sun[62] (see Figs. 8 and 9). Hydrogen present in weld metal in excess of the solubility limit causes the various defects already discussed. The amount of hydrogen which will be present in any given weld depends on the partial pressure of hydrogen in the arc atmosphere, as discussed in a later section. Curves showing this relationship and the effect of the water content of the coating on the hydrogen dissolved in the molten weld deposit are given in Fig. 1.[27]

Hydrogen does not seem to produce aging effects such as are caused by carbon and nitrogen in mild steel. Thus with regard to strain aging, the behavior of low-hydrogen E6016 weld deposits is similar to that of the higher hydrogen E6010, E6012 and E6020 electrode types.[63]

MECHANICAL PROPERTIES OF WELD DEPOSITS

General Considerations

The effects of hydrogen on the mechanical properties may be ascribed to one or a combination of several factors: (1) void spaces and cavities initially present, (2) the internal state of stress and (3) the rate of straining.

It was earlier mentioned that when void spaces, cavities or microcracks are present in the weld deposit or in the heat-affected zone of the base steel, atomic hydrogen is likely to diffuse into these areas and change into the molecular state. This is believed to result in severe internal pressures which are likely to reduce the ductility and toughness of the areas which surround these void spaces. This may explain why weldments made with low-hydrogen electrodes generally show in the as-welded state greater ductility and lower notch-impact transition temperatures than weldments made with other electrodes which supply greater quantities of hydrogen.

High internal stresses, as discussed earlier, are likely to magnify the detrimental effects produced by the formation of molecular hydrogen in the void spaces.

Since straining is generally associated with the formation and movement of dislocations, it may intensify the embrittlement of hydrogen-bearing steels. It is believed that the hydrogen does this by forming molecular hydrogen, under conditions of strain, which is segregated in the dislocations or other lattice defects.[22, 138] Strain-rate tests indicated that, at very high strain rates, the hydrogen did not have time to diffuse and combine into molecular hydrogen.[22, 138]

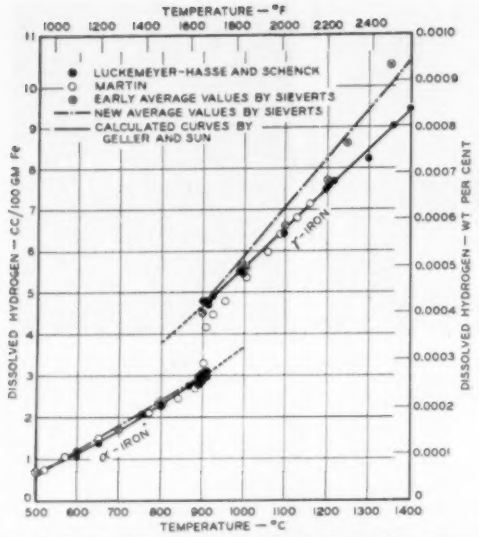
TEMPERATURE — °F
1000 1200 1400 1600 1800 2000 2200 2400
LUCKEMEYER-HASSE AND SCHENCK
MARTIN
EARLY AVERAGE VALUES BY SIEVERTS
NEW AVERAGE VALUES BY SIEVERTS
CALCULATED CURVES BY GELLER AND SUN
γ-IRON
α-IRON
DISSOLVED HYDROGEN — CC/100 GM Fe
DISSOLVED HYDROGEN — WT PER CENT
TEMPERATURE — °C
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Fig. 8 Effect of temperature on the solubility of hydrogen in pure ferrite and austenite at atmospheric pressure[23]

Consequently, the higher strain-rate tests showed very little embrittlement. Thus under these conditions, strain rates approaching impact rates showed no embrittlement, whereas the slower tensile-test strain rates showed maximum embrittlement.[22] This has been observed by various investigators who reported that decreases in the rate of straining or testing increased the embrittlement and raised the number of cracks and fisheyes on the surface of the fractured specimens.[29, 119]

Effects of Fisheyes Upon Embrittlement

It is generally agreed that fisheyes are characteristic of local embrittlement in the weld. In the two theories which are generally suggested, the presence of some hydrogen in the weld metal at the time of fracture is presupposed.[149] The theories are (1) that high pressure hydrogen collects in porosities in the weld metal during cooling and sets up regions of high multiaxial stresses[149] and (2) that when weld metal is strained, hydrogen trapped in lattice defects, or in solution in the metal, diffuses to any porosity in the weld metal and sets up high local pressures and regions of multiaxial stresses.[149] In support of the latter theory it is argued that when the rates of straining are rapid, as in impact tests, diffusion of hydrogen cannot take place rapidly enough, and no fisheyes are observed on the fractured surface.[149] In an impact specimen, however, the position of the fractured surface is determined by the notch and, if only a few porosities are present, the plane of fracture may not pass through any of them.[149] Moreover, the appearance of the fracture of embrittled specimens, after an impact test, makes it difficult to pick out a special embrittled region around the central spot.[149] In fact, Tucker[149] and his associates have observed bright spots on fractured all-weld-metal impact specimens which were almost identical with the central spot of a fisheye. However, since the whole surface showed a brittle fracture, no local brittle fracture regions could be distinguished. Furthermore, tensile tests made at − 95° F. (−70° C.), where the rate of diffusion of hydrogen is presumed to be slow, have also revealed bright cavities on the fractured surface, although here again the whole area was brittle and no local brittle regions (rings) could be distinguished around the bright cavities.[149]

Experiments by Tucker[149] and his associates suggest that the presence of hydrogen in the weld metal at the moment of fracture is not essential, although there must have been hydrogen in the weld metal at some time. In these experiments the welds were prepared with very damp electrodes. The specimens were fractured by bending and, as expected, a large number of fisheyes was observed.[149] Similar specimens were then heated for 3 hr. at 1290° F. (700° C.). These specimens, as shown in Fig. 10, also showed fisheyes in the weld metal after they had been fractured by bending. In fact, fisheyes, though somewhat smaller, were even observed in specimens which had been heated for 24 hr. at 1290° F. (700° C.) and fractured by bending.[149] Since the temperature to which the specimens were heated was sufficient to ensure rapid diffusion of

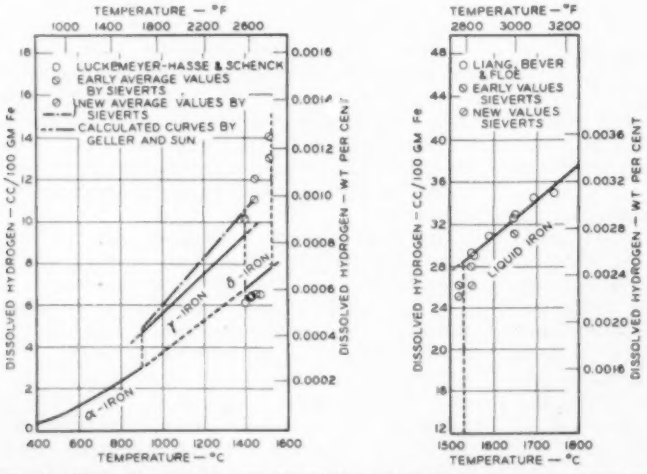

Fig. 9 Effect of temperature on the solubility of hydrogen in ferrite, austenite and molten iron at atmospheric pressure[23]

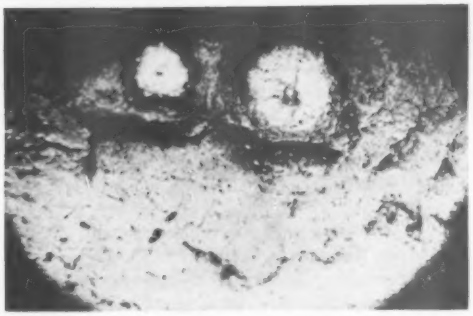

Fig. 10 Fisheyes in weld deposit fractured after heating at 1290° F. (700° C.) for 8 hr.[149] Magnification 10 ×

hydrogen either from the high-pressure gas pockets or from solution in the metal, the fisheyes can hardly have been produced by brittle fractures resulting from multiaxial stresses set up by high-pressure gas.[149] A possible explanation may be that fisheyes exist, before mechanical testing, partly as pockets of gas and partly as zones of disrupted metal.[149] If the steel is heat treated, the gas may diffuse away, but the zone of disrupted metal around the pocket will remain and may cause the appearance of a brittle fracture when the weld is broken.[149] Attempts have been made to confirm this by sectioning weld deposits of a type known to contain fisheyes which have not received any mechanical deformation prior to sectioning. In Fig. 11 a porosity is shown in an as-welded specimen with some evidence of distortion around the porosity.[149] Similarly, Figs. 12 and 13 show distorted metal around the porosities in weld deposits heated for 3 hr. at 1290° F. (700° C.).[149]

Ductility

The reduced ductility in the areas surrounding the void spaces will, in turn, lower the over-all ductility of the weld deposit. Thus Daniels, Gardner and Rood[64] found that the ductility of a low-hydrogen E6016 deposit generally was somewhat greater than that of a deposit made from E6010 electrodes. Their data were based on single-bead deposits. Nevertheless, fisheyes occurred even in fractured tension specimens in both E6016 and E6010 deposits in the as-welded condition. Heating for 24 hr. at 400° F. (205° C.) eliminated fisheyes. Nevertheless, although fisheyes disappeared on proper heat treatment, they would reappear on recharging with hydrogen.[15, 60, 111, 168]

Sims, Moore and Williams[8] noted that ductility losses to levels only 15 to 30% of the ductility of hydrogen-free cast steel were caused by hydrogen in the range 1.3 to 5.1 cc. per 100 gm. (0.0001 to 0.0004% by weight) of steel. This abnormal loss of ductility could be completely eliminated by aging the steel at a temperature of 400 to 500° F. (205 to 260° C.) for at least 12 hr. The hydrogen may be introduced from various sources. For example, hydrogen absorbed from an oxyacetylene flame during pressure welding of concrete reinforcing bars has been observed to cause embrittlement.[67] An anneal at 1500° F. (815° C.) restored the ductility.

The distribution of hydrogen in the weldment may vary with the mode of introduction of hydrogen. Hydrogen introduced by cathodic pickling probably will produce effects somewhat different from hydrogen introduced by welding.[25] Actually, a clear-cut relationship often does not seem to exist between the hydrogen content and the ductility of mild-steel weld deposits. Thus Flanigan,[66] who produced hydrogen-bearing weld deposits by using either normal welding procedures or acid pickling, concluded that either (1) hydrogen is of no importance in normally cooled welds or (2) hydrogen is of importance, but its relationship to ductility is very complex and only a very small portion of the hydrogen content is harmful. Thus it may well be that the distribution and state of the hydrogen, whether atomic or molecular, as well as the internal stresses in the weldment and the rate of straining will

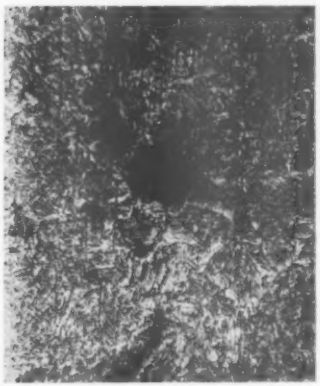

Fig. 11 Gas porosity in unbent weld deposit.[149] Magnification 100 ×

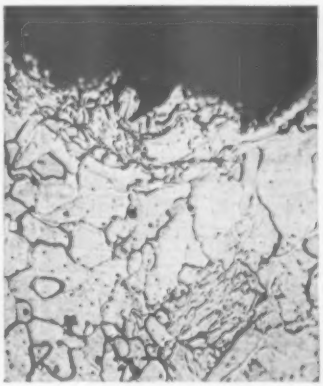

Fig. 12 Distorted metal around gas porosity in unbent weld deposit.[149] Magnification 1000 ×

Fig. 13 Distorted metal around gas porosity in unbent weld deposit.[149] Magnification 1000 ×

determine its effects on ductility and on the other mechanical properties. Analysis of hydrogen alone does not allow for differentiation among these several factors.

Flanigan's bend test also indicated that there was no significant difference among the ductilities of weld deposits made from standard E6010 welding electrodes, low-hydrogen-bearing weld deposits produced by the submerged-arc welding process, and the low-hydrogen welds produced from electrodes having lime-base coatings. These results may have been due to the fact that the E6010 electrodes used did not introduce much hydrogen; some do not. However, these observations may also be explained if it is assumed that hydrogen reduces ductility only when it has changed to the molecular state in the vicinity of void spaces. Thus, if the various types of welds made by Flanigan are all relatively free from voids, reduction in ductility owing to hydrogen may be negligible. Moreover, if hydrogen is introduced into the weld deposits by means of acid pickling, embrittlement occurs near the few existing voids and this may well reduce the ductility of all the weld deposits.

The effect of hydrogen is more pronounced when it is retained in solution down to lower temperatures. Thus Flanigan, Bocarsky and McGuire[66] later studied the effect of low-temperature cooling rates on the ductility of arc welds in mild steel and found that rapid cooling of the weld below 400° F. (205° C.) promoted low ductility because more hydrogen remained in the weld. Low-hydrogen welds subjected to the same conditions appeared immune to this loss of ductility.

Impact Toughness

There is little doubt about the fact that hydrogen tends to reduce the ductility of weldments tested by bending or in tension at ordinary rates of strain.[18] However, there exists considerable disagreement in regard to hydrogen and its relation to impact toughness. Thus, hydrogen, which collects in void spaces, cavities, and other imperfections such as dislocations, is likely to reduce impact toughness and raise the transition temperature characteristics of the steel weldment. On the other hand, hydrogen embrittlement resulting from straining is not encountered in impact specimens. Other factors may also be involved and may be responsible for differences of opinion among various investigators. It should be realized also that in impact testing with a notched specimen the stress gradient as well as the strain rate is at a high level—thus providing embrittling conditions even without hydrogen being present.

Herres and Woodward[5] presented results of many impact tests of welds made with cellulosic and lime-coated electrodes. Some compositions revealed a very severe drop in impact toughness especially at −40° F. (−40° C.), after a weld was stress relieved, and other compositions revealed a less severe, or no, drop. Rarely did stress relieving itself improve impact toughness. There was an indication that a weld made with a lime-coated electrode had better impact strength than one made with a cellulosic-coated electrode. It is peculiar that their data do not reveal the differences between cellulosic- and lime-coated electrodes as significantly as do the results of other investigations. It may well be that the unusually good results obtained with the cellulosic electrodes is due to the carefully controlled welding conditions under which the test specimens were prepared.

Barnett[42] stated that the impact strength of weld metal from lime-ferritic electrodes of the E60XX type at room temperature was more than double the best of the other E60XX classes and retained its advantage at −50° F. (−46° C.).

Mathias and Bunk[21] investigated the impact strength of a lime-ferritic (E6015) deposit in comparison with that of an E6020 deposit. The source of Barnett's information (above) on this subject is probably the same data. A graph showing this comparison is reproduced in Fig. 14.

Daniels, Gardner and Rood[64] found that in the as-welded condition the transition temperature from ductile-to-brittle fracture of E6016 welds is 75 to 100° F. (42 to 55° C.) lower than for E6010 welds. Holding 24 hr. at 400° F. (205° C.), which presumably eliminates most of the hydrogen, did not improve the impact properties of either the E6016 or E6010 welds. This was interpreted as indicating that the hydrogen content of welds does not affect the transition temperatures as determined by impact tests. However, the transition temperatures of their E6016 welds are 75 to 100° F. (42 to 55° C.) lower than the transition temperatures of their E6010 welds which had received the same thermal treatment during and after welding. This would indicate that these differences might be attributable to hydrogen in some complex manner and be related to the effects of solidification and cooling. Additional results by Tucker[149] are given in Table 5. They also show that weld deposits from low-hydrogen lime-ferritic electrodes have markedly superior impact

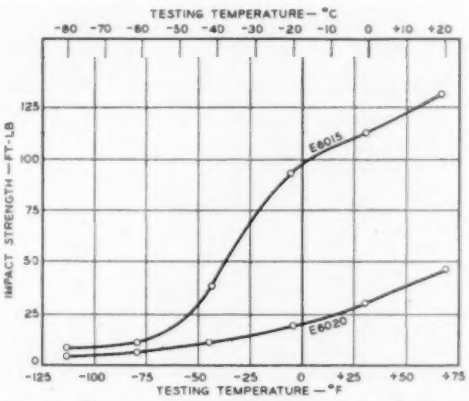

Fig. 14 Effect of testing temperature upon Charpy V-notch impact strength (45° notch, 0.01 in. radius, 0.079 in. deep) of E6015 and E6020 weld deposits[21]

Table 5—Transition Temperatures* and V-Notch Izod Impact Strength of Weld Deposits Made from Different Types of Electrodes[140]

Type of coating	Type of deposit	Transition temperature, ° F.	° C.	Impact strength at transition temp., ft.-lb.
Titania	Mild steel	−22	−30	30
Iron oxide	Mild steel	−31	−35	30
Low hydrogen	Mild steel	−40	−40†	55
Low hydrogen	Alloy steel	−67	−55	44

* The temperature where the impact strength has fallen to one-half that at room temperature.

strength over those deposits made from other types of electrodes. The advantages of the low-hydrogen electrodes are particularly apparent at low temperatures. The transition temperature in Table 5 is the temperature where the impact strength has fallen to one-half that at room temperature.[140]

Fisheyes which may appear in tensile specimens containing a certain minimum quantity of hydrogen are not likely to appear in impact specimens taken from the same welded section.[119]

When excessive quantities of hydrogen cause the formation of porosity in the weld metal during solidification, the impact toughness is likely to be reduced. This is supported by data by Stäger and Held[29] who showed that weld deposits made with electrodes wetted by immersion in water gave somewhat lower toughness values than dry electrodes. The differences, however, were small and Stäger and Held[29] concluded that dissolved hydrogen did not affect impact toughness. The composition of the electrode coating represented a much more important variable than the presence of water.

The only data in conflict with these results were reported by Stout, Doan and co-workers[38] and by Keel.[114] The decrease in Charpy impact strength observed by the former, which was believed to be related to the presence of hydrogen, did not occur in weld specimens, but in specimens made with a "synthesizing heat treatment." No significant effect of hydrogen on transition temperature was found. It was concluded that the effect of hydrogen was second to that of the microstructure.[38] It may well be that the observed reduction of impact energy is, in fact, a manifestation of some other effect than hydrogen or some hydrogen effect not to be found in weld specimens.[18] It might be possible that the differences may be due to the mode of hydrogen introduction into the specimens. The data by Keel[114] on weld metal deposited by oxyacetylene welding are shown in Fig. 15. Curve *A* shows that aging improved the impact toughness and reduced the hydrogen content. Further improvement was obtained by flame heating the weld metal to 1110° F. (600° C.) followed by water quenching.[114]

Mikhalapov[28, 68] conducted laboratory explosion tests on base metals and joints welded with E6010, E7016, E10015 (Mn-Mo), E10015 (Ni-Mo) and E12015 (Ni-Mo-V) electrodes and joints welded by the submerged-arc process. He stated that good correlation was evident between these tests and full-scale tests on hatch corners conducted at the University of California. Using an E6010 electrode, Mikhalapov found that the explosion impact strength of a joint in carbon-manganese steel was only half the impact strength of the prime plate at 30° F. (−1° C.) and one-tenth at −40° F. (−40° C.). With the use of an E7016 electrode, the result was only slightly better than with an E6010 at 30° F. (−1° C.) and no different from an E6010 at −40° F. (−40° C.). He concluded that the impact strength can be greatly improved by the use of the proper alloy electrodes (low-hydrogen types). However, his data indicated that, regardless of the type of electrode used, the impact strength of a welded joint was almost always less than the impact strength of the prime plate. For comparison with the above figures, using the E12015 Ni-Mo-V electrode, the impact strength of the joint in Ni-Cr plate was one-third the strength of the prime

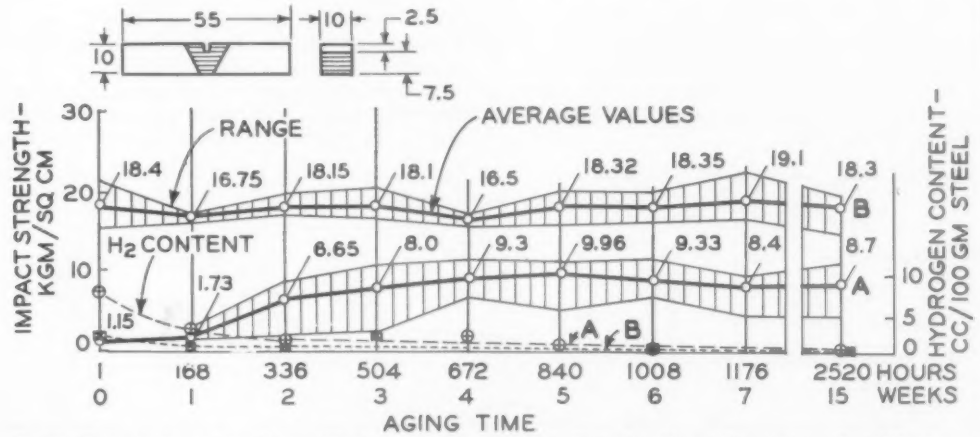

Fig. 15 Change in impact toughness with time. Curve A as-welded; Curve B weldment flame stress relieved 30 min. at 1110° F. (600° C.).[114] (Weld metal composition: 0.17% C, 1.00% Mn, 0.02% Si, 0.018% P, 0.025% S, 0.06% Ni, 0.07% Cu)

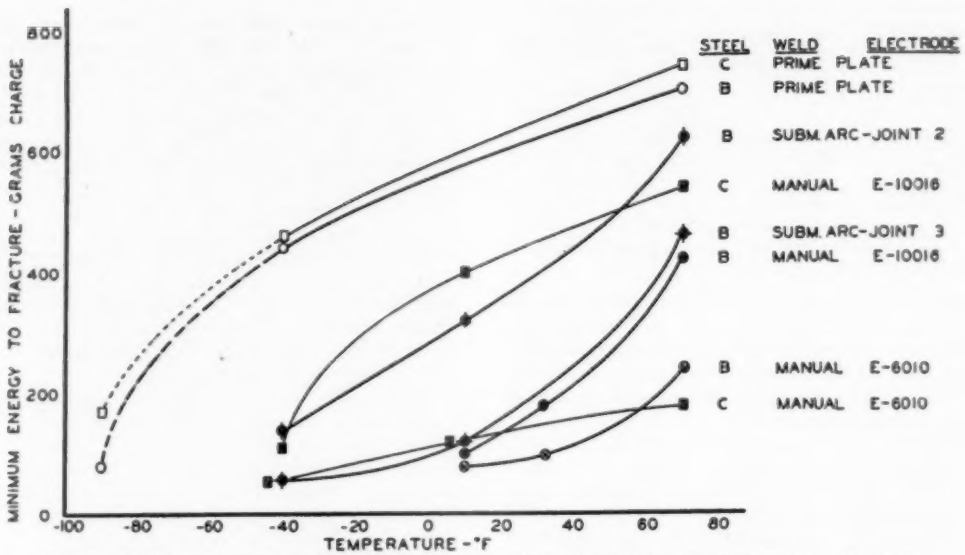

Fig. 16 Effect of temperature on minimum energy to fracture welded and unwelded ship plate 1 in. thick[85]

plate at room temperature and was the same at −90° F. (−70° C.), (no intermediate comparisons given). Similar data for submerged-arc, E10016 and E6010, electrodes are given in Fig. 16.[68] Mikhalapov concluded that the performance of the E10016 electrodes was superior to that of the E6010, both because of the reduction in hydrogen and because of the introduction of nickel and molybdenum. The reduction of the hydrogen content of the submerged-arc weld to nearly zero by the use of a fritted flux was considered to be more important than the reduction of the oxygen content of the plate or the addition of alloying elements.

Fatigue Strength

Since fatigue failures are associated with very slow rates of straining, the fatigue strength may be considerably reduced by the presence of hydrogen in the weldment. Data obtained by Stäger[20, 118] with different dry- and wet-coated electrodes showed reductions between about 5 and 50%.

HYDROGEN CONTENT IN WELD DEPOSITS

General Considerations

In an earlier review, Spraragen and Claussen[69] summarized the information published before July 1, 1938. The reported data indicated that the hydrogen content of weld deposits ordinarily varied between 0.0001 and 0.003% by weight. In a few cases as much as 0.005 weight per cent of hydrogen was reported. The latter, relatively high hydrogen content was observed in deposits produced by arc welding,[8] atomic-hydrogen welding[10] and oxyacetylene welding.[79] Inert-gas welding, on the other hand, produced weld deposits essentially free from hydrogen.[8, 121]

To a considerable extent, the amount of hydrogen in a weld deposit will also depend upon the welding technique employed and the type of electrode used. In arc welding, in particular, the type of electrode coating is important since the total hydrogen content of the weld deposit will be approximately proportional to the total

Table 6—Hydrogen in Electrode Coatings[35, 150]

*Electrode type**	*Per cent of coating*	*Hydrogen in coating* *cc. per 100 gm. of steel*	*%*	*Total hydrogen in weld* *cc. per 100 gm.*	*Weight %†*
L	25.96	1524	0.47	9.2	0.0008
A	20.81	1313	0.58	9.4	0.0008
B	17.82	1904	0.96	14.9	0.0013
G baked 660° F. (350° C.)	20.45	472	0.19	5.8	0.0005
C	20.31	1401	0.62	12.0	0.0011
D	24.36	1383	0.51	21.45	0.0019
G	22.26	1190	0.48	22.5	0.0020
F	11.79	1207	0.92	18.15	0.0016
N	13.07	2850	1.96	20.4	0.0018

* Mild-steel electrodes, arranged in order of deoxidation from most oxidized at top of list to least oxidized at bottom.
† 1.0 cc. hydrogen per 100 gm. steel = 0.0786 RV (relative volume of H_2; 1 RV = 0.00114 weight per cent of H_2.[8]

Table 7—Effects of Electrode Coating on the Hydrogen Content of Arc-Weld Deposits[19]

Electrode Code	Electrode Type	cc H_2 per 100 gm. weld metal: Cold evolution	Warm extraction	Total	Wt. % total*
X1	E6010	15.3	1.7	17.0	0.0015
X3	E6020	14.0	1.5	15.5	0.0014
X9	LHLC†	5.6	1.0	6.6	0.0006
X10	LHLC†	6.6	0.9	7.5	0.0007
X11	LHLC†	2.9	1.8	4.7	0.0004

* 1.0 cc. hydrogen per 100 gm. steel = 0.0786 RV (relative volume) of H_2; 1 RV = 0.00114 weight per cent of H_2[3].
† Low-hydrogen, lime-coated.

available hydrogen in the electrode coating.[71] A part of this hydrogen is held more or less permanently. The remainder escapes from the metal at room temperature. Since to earlier investigators the remaining quantities of hydrogen did not appear to be constant even for the same electrode,[71] there was much confusion and difficulty in the interpretation of results. Thus Reeve[35] reported that the total available hydrogen in the form of free and combined water and organic hydrogen influenced the hydrogen in the weld, but that the relation was not close. Reeve's data are reproduced in Table 6. Results of experiments by Mallett[19] on cellulosic- and lime-coated electrodes are reproduced in Table 7. Reference has already been made (Fig. 1) to Christensen's data.[37]

Similarly, results obtained by various investigators who analyzed weld metals for residual hydrogen content, are shown in Table 8. Rollason found that, if underbead cracking* is to be prevented, the maximum limit appears to be 4 cc. H_2 per 100 gm. (0.00036% by weight) of steel, although reduction to 1 to 2 cc. per 100 gm. (0.00009 to 0.00018% by weight) vastly extends the weldability.

* Underbead cracking describes cracks which occur adjacent to the weld deposit ("under the bead") in the heat-affected zone.

Table 8—Hydrogen Content of Weld Deposits Produced from Various Types of Electrodes[2, 14, 61, 72, 115, 126, 149]

Electrode type		H_2 cc./100 gm. weld metal	Weight %*
E6010	Cellulosic type	8–22	0.0007 –0.0020
E6012	Titania type	7–22	0.0006 –0.0020
E6013	Titania type	4–20	0.0004 –0.0018
E6015	Low-hydrogen type	0.9–4	0.00008–0.0004
E6020	Iron-oxide type	4–16	0.0004 –0.0015
E6030	Iron-oxide type	4–16	0.0004 –0.0015
	Bare wire	2.4	0.0002
18–8 (Cr-Ni) stainless steel—good		8–15	0.0008 –0.0013
18–8 (Cr-Ni) stainless steel—poor		15–32	0.0013 –0.0029

* 1.0 cc. H_2 per 100 gm. of steel = 0.0786 RV (relative volume) of H_2; 1 RV = 0.00114 weight per cent of H_2.[3]

On a weight basis, Herres[20] stated that molten weld metal can and often does absorb well over 0.003% of hydrogen by weight (36 cc. per 100 gm. of weld metal).

In weldments produced by oxyacetylene welding, Keel[114] reported that the hydrogen content varied between about 4 and 12 cc. H_2 per 100 gm. of weld metal (0.0004 and 0.0012%).

Analysis for Hydrogen in Weld Deposits

Various procedures have been suggested for measuring the hydrogen content of weld deposits.[1, 2, 65, 73, 74, 116] Comparison among several of the more popular methods was recently made by Stern, Kalinsky and Fenton,[73] who concluded that after six days at room temperature, almost all of the hydrogen was evolved which would escape from the weld deposits at room temperature conditions. Special postheat treatments would usually be required to remove the hydrogen that is retained within the as-welded specimen at room temperature. Typical results by Flanigan, presented in Fig. 17,

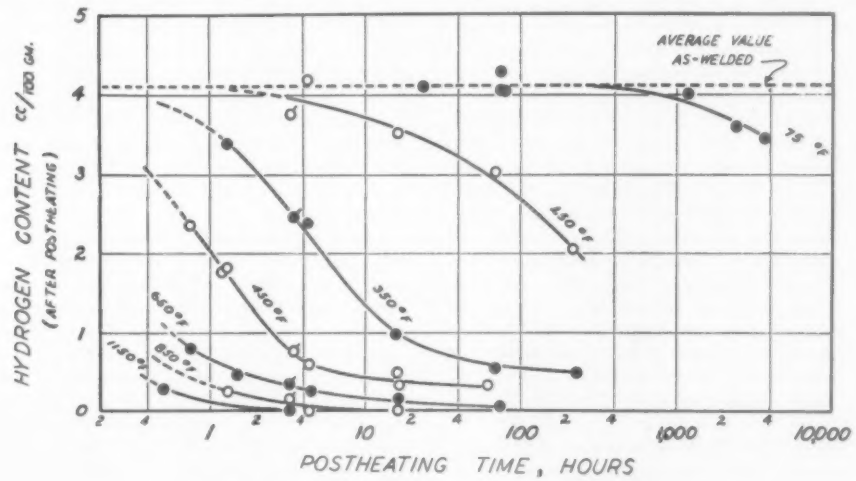

Fig. 17 Effect of postheating on the hydrogen content of E6010 weld metal[65]

indicate the amount of hydrogen that is retained in E6010 weld deposits which would be evolved only upon heating.[65] The period of hydrogen evolution depends very much upon the size and shape of the specimen and the temperature at which the tests are conducted.[147] At the British Welding Research Assn. the tests have been standardized on a temperature of 77° F. (25° C.) since it was found that the rate of hydrogen evolution is reduced many times by a slight temperature decrease of only a few degrees (centigrade).[147] The time required for evolution under these conditions varies from 1 or 2 hrs. to several weeks—depending upon the size of the specimen.[147]

The most commonly used method is based on the collection of the evolved gas over glycerin.[73, 116] This method has been adopted by the latest AWS-ASTM Specifications.[60, 61] The following procedure is generally recommended.[73] The test specimen is put into a eudiometer (gas volume measuring) tube (Fig. 18), which has previously been completely filled with glycerin. The open bottom of this tube remains below the surface of glycerin in a trough of a glycerin-filled tank while the test piece is inserted into the tube. The tube containing the test specimen is then set in an upright position on a shelf inside the tank. The temperature of the glycerin in the tank is maintained thermostatically at approximately 113° F. (45° C.) by means of three 60-w. bulbs placed outside the tank beneath the shelf. The amount of liberated gas is observed and recorded at desired intervals by reading the volume as shown on the graduated stem of the eudiometer tube. This stem is graduated to 8 cc. in 0.1-cc. divisions.

The glycerin method, which has the advantage that it consists of a relatively simple procedure, has been criticized because it does not indicate all of the hydrogen in the weld and because gas bubbles on the specimen interfere with the determination.[73] The more refined procedures, employing vacuum testing and analyzing equipment,[75–83, 109, 124, 135, 137, 175, 177, 180] have been found to yield more than twice as much hydrogen gas as the glycerin and the other cold extraction methods. This is due to the fact that hydrogen in the weld metal appears to be present not only as diffusible hydrogen,* which passes out at room temperature and under normal atmospheric pressure, but also as hydrogen which is retained in the metal.[127] The proportion of the retained hydrogen seems to depend upon the amount and type of nonmetallic particles in the weld metal. If there are many, there is a greater tendency to hold the hydrogen in the weld metal.[127] In addition, the composition of the steel, prior thermal history, degree of cold work, hydrogen pressure and degree of ionization, and other factors are likely to influence the amount of retained hydrogen.[152] The amount of retained hydrogen is generally determined best by vacuum procedures at red heat.[127]

As shown in Table 7, the greater part of hydrogen can be collected during cold evolution. Since the cold cracking attributed to hydrogen occurs during the period when "cold evolution" is taking place, the use of a method determining the rate and quantity of hydrogen evolved at room temperature which is more accurate than the erratic glycerin method and less expensive and easier to operate than the highly refined vacuum fusion method should have certain advantages. Such a method was recently developed by Stern, Kalinsky and Fenton[73] and consists of placing the specimen into a combustion chamber in a closed evacuated system, kept at a constant temperature, and determining the hydrogen evolution by means of a cupric oxide anhydrone analyzer.

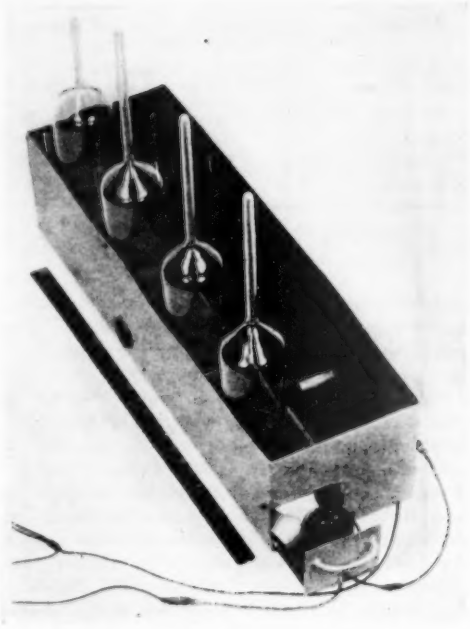

Fig. 18 Eudiometers and gas-collecting liquid reservoir[73]

Another procedure used in the rapid approximation of hydrogen content consists of giving the specimen an enamel coat and observing the distribution, number and size of blisters and craters which develop in the enamel coat.[125]

As Larsen pointed out,[76] in any determination of the hydrogen content of steel it is most important to collect the gas as soon as possible. Considerable variation in results will occur whenever the time after welding is an uncontrolled variable. The U. S. Navy Department, which originally specified the glycerin test,[84] now recommends analysis of the covering of low-hydrogen electrodes for total water content (hygroscopic and combined.[36, 85] The justification for this is the demonstration by Reeve[35, 85] and others[71] that the total hydrogen content of weld deposits is roughly proportional to the total water content of the coverings of mineral-covered, shielded-arc welding electrodes. The total water

* The amount of diffusible hydrogen in the weld metal may determine or influence the appearance of underbead cracks in hardenable steels.[180]

must be determined since the hygroscopic moisture is not a measure of the hydrogen content of the weld.[22, 26] A temperature of 2400° F. (1315° C.) has been recommended by Gayley and Wooding[26] to be sure of complete liberation of all combined water through complete calcination of the covering ingredients. Their combustion train is shown diagramatically in Fig. 19. Sloman, Rooney and Schofield[71] had earlier found that 2190° F. (1200° C.) was sufficient to insure a total yield of moisture; in their tests at least 80% of the water was evolved at 1110° F. (600° C.). Since 2400° F. (1315° C.) is quite destructive to furnace equipment and combustion tubes and boats, it may be that some lower temperature will be chosen by laboratories engaged in routine control work.

As shown by Franks, Gayley and Wooding,[27] and incorporated in the most recent low-hydrogen electrode specifications,[26] the total water content in a mineral-type coating should be less than 0.2 to 0.8% (the maximum permissible quantity depending upon the grade) if the electrodes are to perform satisfactorily in severely stressed applications.

WELDING CONSIDERATIONS

Hydrogen should by no means be regarded as the only or even the major factor which causes cracking in welded sections. In fact, according to Zeyen,[144] welds made from low-hydrogen electrodes may sometimes be quite susceptible to the formation of fisheyes so that, sometimes, causes other than hydrogen, which are not yet understood, may be responsible for fisheyes.

When hydrogen is present, it generally is a contributory factor to other causes such as hard and/or brittle zones, the austenite-ferrite or austenite-martensite transformation, multiaxial shrinkage stresses, etc.[16, 28, 87] All these tend to set up micro- or macrostresses within the steel. The presence of hydrogen would increase internal stresses still further and may, in many instances, lead to failure. Consequently, the elimination of hydrogen may be particularly desirable or necessary in those sections in which internal stresses are already appreciable.

In most ordinary welding operations on mild steels, the use of the special low-hydrogen electrodes may not be necessary. However, when hardenable steels are welded or when shrinkage or other factors set up severe multiaxial residual stresses, the use of low-hydrogen electrodes may be advisable or even essential.[5, 20, 27]

In most cases, cracking occurs in the heat-affected zone immediately adjacent to the weld deposit. This is known as *underbead cracking.*[2, 61, 88] However, in a few cases, cracking may occur also within the weld deposit.

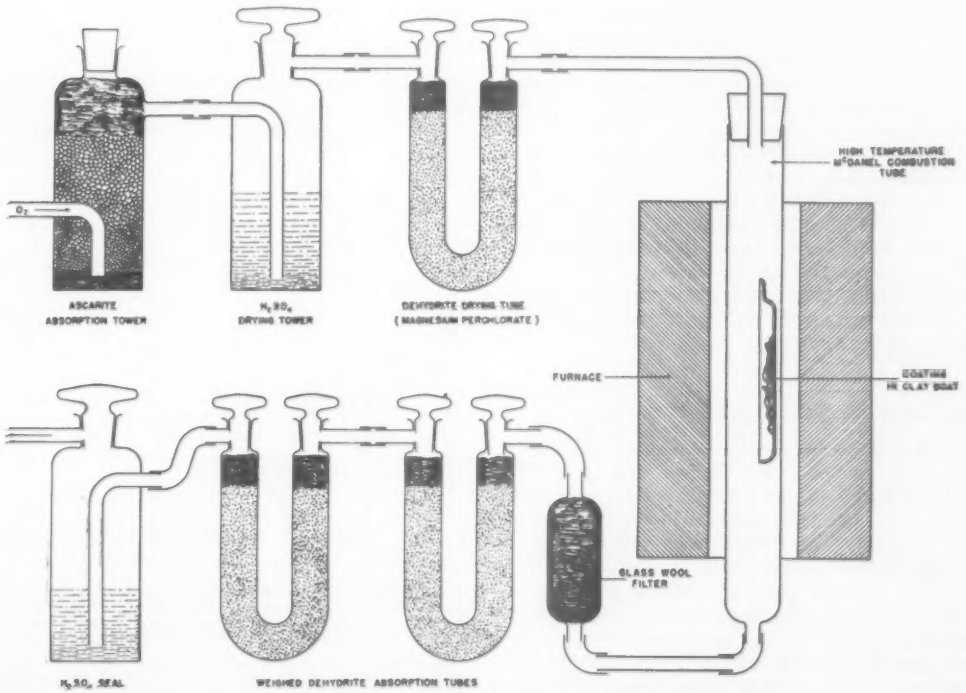

Fig. 19 Schematic drawing of equipment for water determination[26]

Weld-Metal Cracking

Most weld deposits made from mild-steel electrodes are relatively ductile. Nevertheless, microcracks may often occur in practice in weld metal deposited on mild steel.[25, 66, 95] These cracks, however, are generally extremely small and are not readily recognized by microscopic means. However, under extremely severe cooling conditions such cracks may also reach dangerous proportions.[51, 147] Thus although considerable internal pressure may be built up by absorbed hydrogen when using cellulosic-coated electrodes, the weld metal generally relieves the internal pressures by yielding locally and, therefore, does not rupture. However, cracking of tack welds and crater cracking of ordinary mild steel weld beads may become serious under conditions of severe restraint.[152]

Hot cracking in mild-steel weld deposits, however, can be quite serious. Generally it is associated with the presence of iron sulphide which has a lower melting point than the steel. During the final stages of solidification of the weld metal, a liquid film relatively high in sulphur will temporarily remain between the solidified dendrites as the deposit cools down to about 2000° F. (1095° C.). Since this film offers little or no resistance to shrinkage contraction, it allows the metal to be pulled apart resulting in the formation of hot cracks.[24, 87, 101, 102]

The better class of mild-steel electrodes which are manufactured today generally are not susceptible to hot cracking under normal welding conditions. However, when the base steel contains abnormally large amounts of sulphur, as is the case with free-cutting steels, hot cracking may occur. In these cases, the use of low-hydrogen electrodes is recommended,[21, 80, 127] although Claussen[46] stated that the EXX15 type of coating did not prevent hot cracks from forming when the sulphur content was high. Other investigators have also reported conflicting claims on the suitability of low-hydrogen electrodes for high-sulphur steels. Buttering of the groove surfaces in the high-sulphur steel also will decrease the cracking tendency.[146]

Hot cracks in the base metal, visible at the edge of the weld at about 1290° F. (700° C.), were traced to sulphur by Werner.[102]

Heat-Affected Zone (Underbead) Cracking

Underbead cracking describes cracking which occurs in the heat-affected zone of the base steel adjacent to the weld deposit. It is found only in hardenable alloy steels which undergo the austenite-to-martensite transformation. For this reason underbead cracking is treated in detail in the review on alloy steel weldments.[100] It should be realized, however, that the weld metal itself is often deposited from ordinary mild-steel electrodes. These contain hydrogen-forming ingredients, and the hydrogen, upon diffusion into the alloy steel, causes cracking during the austenite-to-martensite transformation.

Composition

Killed steels, in which medium amounts of aluminum were used for steel deoxidation, seem to be highly susceptible to underbead cracking. However, the use of more than 4 lb. of aluminum per ton in steel reduces cracking.[92] In killed steels, the use of cellulosic-coated electrodes seems undesirable, particularly when slow welding speeds and low amperages are used. Under these conditions, increased porosity of the weld may be caused. However, when mineral-coated electrodes, such as the low-hydrogen types, are used, the killed steels with up to 0.20% aluminum prove to be as weldable as the rimmed or other aluminum-free steel types. Welds in aluminum-killed steels exhibit no increased susceptibility to the absorption of hydrogen. Moreover, no increased tendency to hydrogen embrittlement can be noted.[55, 93]

The effects on crack sensitivity of welding with cellulosic-type electrodes (class E6010) and the composition of mild and medium-carbon steels are indicated in Fig. 20.[90, 94] When the carbon, manganese and/or silicon content are increased, crack sensitivity will also increase. (As is indicated by the equation for the carbon equivalent factor, manganese and silicon seem to be about one-fourth as effective as carbon in this respect.) When low-hydrogen electrodes (Class E6015) were used, underbead cracking was prevented, even though the values for bending angle and underbead hardness did not change.[90, 94]

Microstructure

The microstructure of the base steel also represents an important factor in underbead cracking. For example, a coarse carbide structure seems to be superior

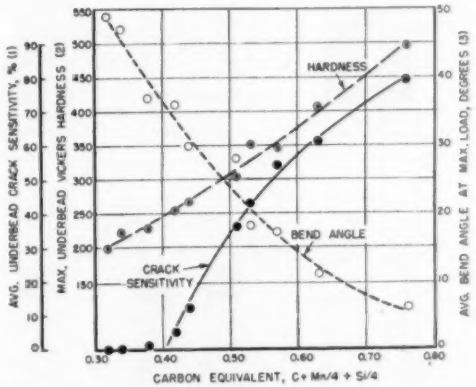

Fig. 20 Relation between steel composition and underbead hardness, crack sensitivity and notched-bead bend angle, for 1-in. plates of the commercial rolled carbon-manganese steels welded with class E6010 electrodes[90, 94]

(1) Average of tests at room temp., 150 and 225° F. (65 and 105° C.) preheat treatments (heat input 16,000 joules/in.); (2) maximum hardness under 3-in. beads, 75° F. (25° C.) preheat (heat input 56,000 joules/in.); (3) bend angle for 5/32-in. beads, 75° F. (25° C.) preheat (heat input 47,000 joules/in.)

to one in which carbides are finely dispersed, probably because small finely distributed carbides are more readily soluble than coarse carbides and thus increase hardenability more during the short welding heat treatment. Moreover, undesirable structural features in the heat-affected zone or in the weld metal may be more detrimental than the presence of above average amounts of hydrogen. Thus, a variation in the cooling rate or certain pre- or postheat treatments may have a greater effect on the bend angle of bend-test specimens than does high or low hydrogen in the weld metal.[109]

Cast steels seem to be less susceptible to underbead cracking than wrought steels of similar composition.[90, 94]

Cooling Rate After Welding

Generally, susceptibility to underbead cracking increases as the cooling rate is increased.[51, 90] This is probably due to the fact that (1) the more rapid the cooling rate the greater is the amount of hydrogen that is retained in the weld metal, (2) the residual stresses generally increase with cooling rate and (3) a greater amount of martensite is formed. These effects may then cause cracking—particularly upon the ultimate transformation of the retained austenite.

Preheating decreases cooling rates and thus more hydrogen is likely to escape.[94] Nevertheless, results by Flanigan[65] reproduced in Fig. 21 showed that in spite of the fact that slower cooling rates are obtained through the use of preheat treatments, the hydrogen content of the preheated weldments was greater than those made at room temperature. Ductility, however, seemed somewhat improved by the preheat treatment. The slower cooling rates are also beneficial in that they minimize the residual stresses and increase transformation to the medium and high-temperature transformation products.[25, 51]

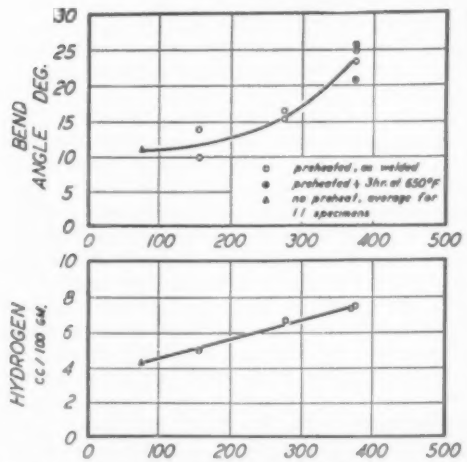

Fig. 21 Effects of preheating on ductility and hydrogen content of E6010 welds[65]

Arresting the cooling and postheating at a predetermined temperature also promotes transformation to the medium- and high-temperature transformation products and permits hydrogen to escape before it can cause any damage to the weldment.[152] This is far more effective in preventing cracking than any stress relief or postheating treatment which is not accompanied by arrested cooling. In the conventional postheat or stress relief treatments, the weld is first allowed to cool fully or partially with the consequence that hydrogen has the opportunity to cause damage and no amount of subsequent heat treatment can rectify this situation.[152]

Effect of Cooling Rate on Weld Ductility

In addition to underbead cracking, an embrittling effect of hydrogen can be detected in many welds. The ductility of cellulosic-type E6010 welds has thus been shown to depend on the cooling rate of the weld below 400° F. (205° C.), rapid cooling promoting low ductility.[66] Low-hydrogen welds made under the same conditions appeared immune to embrittlement.

Both E6010 and low-hydrogen E6016 welds were shown to have the same yield strength and ultimate tensile strength if the preheat and energy inputs were adjusted to give the same cooling rates at 1000° F. (540° C.), but the elongation of the E6016 welds was consistently equal to or greater than the elongation of the E6010 welds.[64] The cooling rates which were studied are relatively slow in this case [15° F. per second (8.5° C. per second)] and no great restraint was put on the welds, so that only slight differences in hydrogen content are apt to have remained after these welds cooled. More recently Nippes[98] pointed out that low-hydrogen E6016 electrodes were superior to the cellulosic coated electrodes only with moderate or low energy inputs and in weldments which were not preheated. It will be recognized that these are the conditions which cause rapid cooling rates, thereby preventing the escape of the hydrogen introduced by the cellulosic electrode.

Related to cooling rate is the "quench time," that is, the length of time the weld is allowed to cool in air before being quenched in water as required by various specifications.[38, 40, 41, 84] Bland[95] studied the effect of postwelding quench time on the ductility of all-weld-metal test bars prepared with E6011 electrodes. Although he had no data on the hydrogen content of his welds, Bland recognized the effect of a critical quantity of hydrogen.

Postwelding Heat Treatment

Heat treatment of the complete weld will tend to restore the ductility of the weld metal in so far as the hydrogen is removed before it has caused microfissuring or cracking. Thus Weck[97] pointed out that an anneal between 1100 and 1200° F. (595 and 650° C.) relieved stresses, made the material more ductile and prevented

temper and hydrogen embrittlement. Nippes[36] pointed out that stress-relief annealing at 1100° F. (595° C.) even for 1 hr. improved the behavior of the weldment sufficiently to approach that of the unwelded plate. Flanigan[15] studied the effects of postheating in the temperature range 250 to 1150° F. (120 to 620° C.) and followed the effect of such treatment on hardness, residual stress, hydrogen content and ductility of the weld.

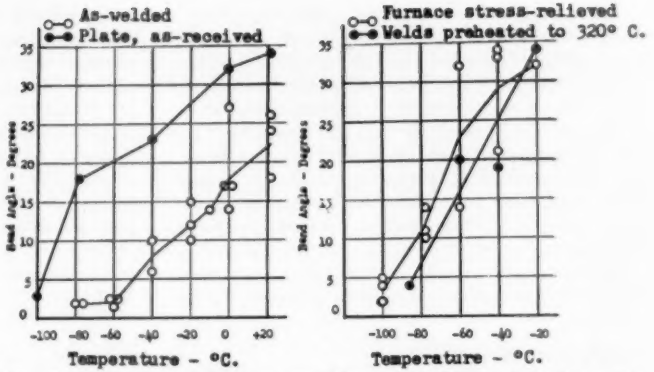

Fig. 22 Transition-temperature curves for as-welded and prime plate specimens, and the effect of furnace stress relieving and preheating on bead welds[39]

If the cooling rate of the weld has been extremely rapid or if the crack sensitivity of the weld metal or heat-affected zone is high, the weldments with high-hydrogen content may contain microfissures similar to hair-line cracks. The presence of these fissures will prevent complete restoration of ductility on tempering, even if temperatures as high as 1200° F. (650° C.) are used.[51, 96] However, just short of the conditions that cause microfissuring, beneficial affects of postheating can be detected. The boundary conditions are most readily detected in the field of alloy welding. For example, SAE Type 4330 steel exhibits greater tendencies toward cracking when postheat treated below or above 600° F. (315° C.) than when treated at 600° F. (315° C.). Sims,[98] in discussing this point, referred to the "S curve" for Type 4330 steel to show that, for this steel, 600° F. (315° C.) is the most favorable temperature for the rapid (15 to 20 minutes) and complete transformation of austenite. At 500° F. (260° C.) and at 700° F. (370° C.) this transformation would take five times as long. Sims[98] pointed out clearly that a successful postheat treatment must transform the austenite at a temperature sufficiently high so that the dissolved hydrogen can diffuse fast enough to prevent the building up of high pressures. A review of the reports of the *Hairline Crack* and the *Alloy Steel Committees* of the British Iron and Steel Institute, released between 1938 and 1950, suggests[100] that a threshold or delay effect occurs in the formation of hairline cracks which may vary from minutes to hours after cooling according to the composition of the steel. Treatment to remove hydrogen within this delay period will eliminate cracking. Moreover, each steel grade has an optimum temperature for the evolution of hydrogen; the preferable hydrogen-removal temperature for one steel may not be effective on a steel of different composition. This may be a contributing factor to the lack of agreement present in the data reported for postheating.[160]

Swan, Lytle and McKinsey[99] studied the effect of the low-temperature stress-relief process which is accomplished by progressive heating of the plate metal alongside the weld to 350 to 400° F. (175 to 205° C.) by oxyacetylene flames. They found no change in the as-welded impact properties of E6010 welds, presumably because of a low-hydrogen content through aging prior to testing (they did not measure the hydrogen). They concluded that there was no appreciable metallurgical effect, harmful or otherwise, from the heating or straining accompanying this low-temperature stress-relieving process.

Although some of the early investigators believed that the effect of hydrogen may be readily detected by Charpy impact tests,[38] it seems now that the results of impact tests cannot be correlated with hydrogen content. Thus results by Daniels, Gardner and Rood[64] indicated that postheating, which, as Flanigan[65] has shown, reduces hydrogen to a very low value, does not significantly alter the impact energy absorbed or the ductile-to-brittle transition temperature of welded specimens.* Data by several other investigators corroborate these results.[5, 99] If hydrogen is removed and no alteration in impact properties is observed, then it cannot be stated that hydrogen is readily detected in weld specimens by Charpy or other impact tests.[18] This agrees with recent studies by Seabrook, Grant and Carney[22] who showed that the effects of hydrogen in SAE 1020 tensile bars decreased as the strain rate was increased.

Preheat and postheat treatments which lower the hydrogen content of the weld are beneficial to bending properties. This may well be related to the relatively slow rates of straining employed in bend tests. Thus Swan, Lytle and McKinsey,[99] who studied E6010 welds on ASTM A201 steel, found that 600° F. (315° C.) preheating and 1200° F. (650° C.) stress-relief annealing lowered the transition temperature appreciably. Their curves showing bend angles for as-welded and prime plate specimens and the effects of furnace stress relieving and of preheating of weld beads are shown in Fig. 22. Their transition temperature curves showing the effects of heating, cooling and straining of weld beads are shown in Fig. 23.

* Nevertheless, in many weld metals a decrease in the impact strength may be expected upon a tempering treatment between 390 and 570° F. (200 and 300°) C.[1] which may be negligible or of considerable magnitude for the different weld metal types.[122] Whether this decrease is the result of an aging effect or of other structural changes has not been settled.[122]

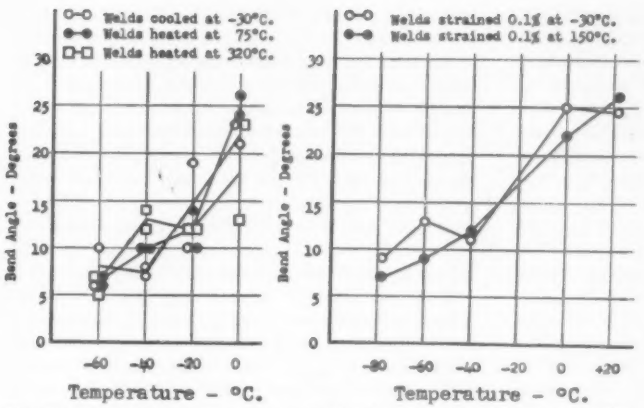
Welds cooled at -30°C.
Welds heated at 75°C.
Welds heated at 320°C.
Bend Angle - Degrees
Temperature - °C.
Welds strained 0.1% at -30°C.
Welds strained 0.1% at 150°C.
Bend Angle - Degrees
Temperature - °C.

Fig. 23 Transition-temperature curves showing the effect of heating, cooling and straining on bead welds[79]

PRACTICAL APPLICATIONS AND ENGINEERING RECOMMENDATIONS

Choice of Electrodes

At the present stage of development of the electrode art, well-defined fields of application exist for "hydrogen-bearing" electrodes (the conventional mild-steel types), and for low-hydrogen electrodes, in addition to an expanding field in which the two types overlap. The conventional mild-steel types are less expensive in first cost and so are the natural choice for all the simpler applications. EXX10, EXX11, EXX12, EXX13, EXX20 or EXX30 electrodes may be used, depending on the type of weld which is to be made. The low-hydrogen types of electrodes EXX15 and EXX16 are more expensive per pound of weld and hence are used more in critical applications which would be adversely affected by hydrogen. Thus, many manufacturers use the low-hydrogen types of electrodes to weld those critical locations in structures which may be subjected to low-temperature impact during service.[140]

For reasons of convenience in stocking electrodes, some fabricators employ low-hydrogen electrodes for all mild-steel welding. Three major considerations must be weighed before this step is taken.

1. In some cases such a choice may reduce the shop productivity. At the same current values, low-hydrogen electrodes have somewhat slower burn-off rates than conventional mild-steel electrodes. On the other hand, higher currents can usually be used with low-hydrogen electrodes than with most mild-steel electrodes and thus about the same burn-off rate can be produced. However, when higher currents are used the slag may be extremely difficult to remove.[140] This is particularly undesirable in multipass welds which must be cleaned thoroughly between passes to prevent slag entrapment.[140]

2. The substitution of low-hydrogen electrodes may necessitate major changes in weld-groove preparation or fit-up. Low-hydrogen electrodes give shallow penetration, which is especially desirable on high-carbon or low-alloy steels where the carbon or alloy pickup from the base metal should be minimized. The groove preparation should be modified to allow for the shallow penetration, by using wider root openings and narrow root faces, for example. The fit-up should also be held to closer tolerances than those required with other mild-steel grades if completely sound high-quality welds are to be obtained with low-hydrogen electrodes.

3. For critical work, it is highly desirable to train operators on the short-arc characteristics of low-hydrogen electrodes and in the correct procedure for striking and breaking the arc.[156] On highly hardenable materials, sidewall wash, undercut and penetration require close attention.[156] If the work is to be inspected under codes, new qualifications for welders will be required unless they are already qualified on stainless-steel electrodes.

The cost of changes in groove preparation, reduced fit-up tolerances and requalification of welders is offset by several advantages to the fabricator. When using low-alloy or high-carbon steels, preheat treatment can be eliminated and thus save a costly operation and reduce operator discomfort and fatigue. Furthermore, the welds will have superior ductility and impact properties. The elimination of only one defective weld, whether it is determined during final inspection or, especially, discovered during service, may completely offset the costs mentioned. Finally, where many types of ordinary and low-alloy steels are handled, the use of low-hydrogen electrodes for all steel welding may be justified by the reduction in the electrode inventory from many types to one type.

Salvaging mild-steel and low-alloy castings by the welding repair of defects has been discussed by Bellew.[166] He reported that foundries chose the EXX10 types of electrodes to cover the great share of the general run of repairs. These were their all-purpose electrodes. They chose the EXX12 electrodes for work which could be positioned to take advantage of the high deposition rates of these electrodes. This type of electrode was chosen for speed. For the best quality welds, however, the foundries chose the EXX16 types of electrodes. EXX16 electrodes were also chosen for work on castings of tricky or dubious analysis or in cases where weld cracking might be a potential problem.

Storage of Electrodes

The "hydrogen-bearing" conventional types of mild-steel electrodes have never been considered a storage

problem by most users. There is to be sure an optimum moisture content for many of the grades, which is best maintained by the manufacturer's original package, but the electrodes will still operate satisfactorily after being exposed to a wide variety of atmospheric conditions. However, if these electrodes are overdried in an effort to eliminate the water, the result may be high spatter loss and often unexpected porosity.

The low-hydrogen electrodes must be stored under conditions which will prevent the absorption of moisture. Objectionable quantities of moisture can be absorbed by low-hydrogen electrode coatings during humid weather, even in a 24-hr. period, if the electrodes are unprotected. For example, after 15 min. at 70° F. (21° C.) and 88% relative humidity, the moisture in a special high-strength low-hydrogen coating is over the 0.2% limit.[143] The manufacturers have recognized this problem and are now packing their electrodes in small unit containers so that the user need not open a large quantity of electrodes to the atmosphere when only a small quantity is needed on a job. Hermetically sealed containers (cans) are usually needed when storage exceeds 3 months.[148] Otherwise storage should be in a heated room.[148] In fact, even when low-hydrogen electrodes have just been removed from hermetically sealed shipping containers, pin holes and porosity may occur unless predrying is employed.[152] Thus, it is recommended practice to bake low-hydrogen electrodes at about 600° F. (315° C.) for 2 hr. and then to store them in a drying oven heated at about 150° F. (65° C.) until they are used.[152]

Excessively long exposure of low-hydrogen electrodes to a humid atmosphere may result in impairment of the electrode beyond the mere absorption of moisture.[150] Prolonged exposure to the humid atmosphere will ultimately destroy the binder through the reaction of carbon dioxide. Low-hydrogen electrodes should be redried in accordance with directions of the manufacturer. Unduly high temperatures may result in the destruction of certain coating ingredients.[150]

A common redrying schedule is 2-hr. baking at 300° F. (150° C.) which will remove the moisture but not combined H_2O.[148] However, these electrodes, when exposed to humid conditions, take on moisture not only by absorption but also by chemical combination.[148] To remove the combined H_2O, drying for about 2 hr. at temperatures as high as 900° F. (480° C.) may be required[146, 148] and may be accomplished with many commercial electrodes without sacrificing usability characteristics or without causing the coatings to become fragile. Such high temperatures would not normally be needed, but certain extremely critical steels welded under unusual conditions, such as high restraint or subfreezing conditions, might require such extreme redrying temperatures.

Preheat Treatment

In the mild-steel applications where severe restraint is not introduced, neither preheat nor postheat treatments are required when dry low-hydrogen electrodes are used.

Preheating is used when underbead or weld cracking might otherwise occur. A preheat treatment is not usually necessary when using the low-hydrogen-coated electrodes. When using conventional mild-steel electrodes, the use of a preheat treatment serves three purposes: (1) the hydrogen is allowed to diffuse to less critical zones in the steel and thus the concentration in the hardened zone is lowered, (2) the transformation occurs at higher temperatures and minimizes the retention of islands of austenite in which hydrogen tends to concentrate, later to cause embrittlement when the austenite transforms at atmospheric or lower temperatures and (3) the cooling stresses are reduced and thus the strains in the heat-affected zones, which could otherwise add to the strains induced by the hydrogen, are decreased. Another benefit is the lowering of the transition temperature as a result of preheating which results in less hardening and greater ductility in the heat-affected zone.

Underbead cracking virtually never occurs with properly designed low-hydrogen types of mild-steel or low-alloy electrodes. Therefore, preheating for elimination of this type of cracking is entirely unnecessary. Wherever unusually high restraint may be encountered, such as when welding heavy sections, it may be necessary to use a preheat treatment to avoid weld-metal cracks. This is more often required with the low-alloy, high-strength electrodes, such as E9016, E11016, etc., than with those of the most commonly used E7016 electrodes. Even so, the temperature of the preheat treatment is usually several hundred degrees lower than that required for the elimination of underbead cracking with conventional types of mild-steel electrodes.

Postheat Treatment

The need for stress relieving after welding will depend upon many factors, such as relief of stress, dimensional stability for machining, reduction of hardness, restoration of the original transition temperature which has been raised by cold working, flame cutting and welding and, last but not least, the type of electrode which has been used. Stress relieving after welding will not improve the properties of welds from low-hydrogen types of electrodes to the same degree as welds from ordinary mild-steel electrodes. The as-welded ductility of the low-hydrogen types of electrodes is only slightly improved by a stress-relieving treatment and is entirely adequate to meet requirements without any postheat treatment.

In ordinary mild-steel weld deposits, fisheyes and fissures are frequently observed in as-welded tensile specimens and their presence results in subnormal ductility. These defects, resulting from hydrogen in the weld metal, may not be observed in certain stress-relieved specimens where the elongation values may be increased 5 to 8%. The absence of this type of defect

in deposits from low-hydrogen electrodes gives as-welded elongation values even higher than the ductility from comparable strength deposits from conventional electrodes in the stress-relieved condition. Only slightly improved values are, therefore, obtained when low-hydrogen welds are stress relieved. In fact microcracks caused by too rapid cooling rates at temperatures below about 500° F. (260° C.) are not removed by thermal stress-relieving treatments[55]—or even by a 1600° F. (870° C.) anneal.[25]

Frequently, it is unnecessary to stress relieve ordinary steel weldments joined by low-hydrogen electrodes. A stress-relieving heat treatment usually serves two purposes: (1) the improvement in the properties of the weld metal by the removal of hydrogen;* and (2) the relief of the residual stresses resulting from the welding operation. In structures where the residual welding stresses are unimportant to its serviceability, there is no need to stress relieve low-hydrogen welds because the weld metal possesses excellent mechanical properties in the as-welded condition and little further improvement will result from the postheat treatment.

Welds in the hardenable types of low-alloy steels will be discussed in another paper.[100] The low-alloy steels become hardened in the heat-affected zone adjacent to the weld. In many low-alloy steel structures it would be desirable to temper the hardened heat-affected zone by a stress-relief postheat treatment to reduce the hardness of the heat-affected zone. Even so, many structures have been successfully built from hardenable low-alloy steels using low-hydrogen electrodes and no preheating or postwelding heat treatments.

Applications

Five major fields of application are recognized for the low-hydrogen types of electrode.

1. Weldments which require the use of preheat treatments may be successfully welded using the low-hydrogen electrodes and preheat treatments about 200° F. (95° C.) lower than those required for the standard electrode types.

2. Sulphur- or selenium-bearing, free-machining steels either must be welded with low-hydrogen electrodes,[21] or the surfaces must be buttered before the weld is made.[145] Conventional mild-steel electrodes give extremely porous deposits when welding free-machining steels. Porosity in such cases, resulting from a combined action of sulphur or selenium and hydrogen, is minimized by the use of low-hydrogen electrodes.

3. In welding steels which are to be enameled, it is particularly advantageous to use low-hydrogen type electrodes.[6, 91, 107, 108, 126, 178] When ordinary electrodes are used, the enamel coating is likely to contain blisters, "fishscaling" or pock marks not only over the entire weld area, but also fairly well over the entire surface of the enameled plate.[176, 179] This is believed [91, 107] to be due to the fact that the hydrogen has migrated into the plate material just as it tends to come out of the weld metal. Since the E6015 type of weld deposit is particularly free from hydrogen, trouble from defective porcelain enameling over welded areas is eliminated. However, as Barnett[107] pointed out, about two-thirds of all sheet-metal welding is performed with E6013 electrodes and other jobs are welded with E6010 and E6011 electrodes. To prevent the liberation of hydrogen during the enameling process such parts must be heated at 700° F. (370° C.) for at least 1 hr. in order to drive out the hydrogen. The customary stress-relieving operation at 1150° F. (620° C.) for 1 hr. per inch of thickness will also remove the hydrogen. Obviously, if the heat treatment is an additional operation, it is an additional expense. For that reason the use of E6015 electrodes offers definite advantages in the field of enameling.

4. Since low-hydrogen electrodes can be used on high-carbon steels, it is reasonable to apply these electrodes to cast iron.[6] The resulting weld deposits will be substantially harder than corresponding deposits on high-carbon steel because of the higher carbon content of cast iron and because the penetration generally will be greater in the lower-melting cast iron. The weld deposits will not be machinable, but should compare favorably with other nonmachinable cast-iron electrode deposits.

5. The use of low-hydrogen electrodes in welding of heavily scaled or galvanized steel will minimize the formation of excessively porous (wormhole type) welds, especially in fillet joints.[170]

6. Weld structures requiring good impact properties at service temperatures below 32° F. (0° C.) should be welded with low-hydrogen electrodes.[21]

FIELDS FOR FURTHER STUDY

There is still need for further information on the study of weld metal produced in a concentrated atmosphere of hydrogen as is present when welding with atomic hydrogen or with high cellulosic or hydrogen producing coatings. Weld metal produced under these conditions and compared with the weld metal produced in a hydrogen-free atmosphere may reveal information that is not presently available. It is not yet clearly established why very good results are generally obtained with atomic hydrogen shielded welding in view of the very detrimental effects of hydrogen with the metallic arc.[142]

Atomistic studies of the distribution of hydrogen in ferrite, martensite and austenite should also be desirable, particularly since no one theory has been universally accepted.

The problem of diffusible and nondiffusible hydrogen should also be studied further.[154] It has been sug-

* However, stress-relief heating is not effective or necessary for removing hydrogen from weld metal—most of the hydrogen is gone within the first few hours after welding or may already have done damage not remedial by stress relief. On the other hand, high-pressure molecular hydrogen, which has been trapped in voids or cavities does not always escape during storage. Thus, fisheyes may, in some cases, be seen in the fractures of tensile specimens of as-deposited weld metal even after the specimens have been stored for half a year or longer.[174]

gested that the quantity of diffusible hydrogen is inversely related to the iron oxide content of the weld metal.[150] However, it might be more closely related to microfissures or porosity or inclusion content.[154] Since diffusible hydrogen seems to be far more important than nondiffusible hydrogen, further investigations of the differences between them are advisable.[154]

Studies should be made to determine the susceptibility of electrode coatings to moisture absorption under various atmospheric conditions of temperature and relative humidity.[145] Although many studies have been made of the weld metal resulting from hydrogen and low-hydrogen bearing electrodes, little attention seems to have been given to finding out how the electrodes should be handled in use to avoid the troubles arising from possible moisture pickup. The relation of this characteristic of coating to the chemistry of the coating is a fundamental factor and little seems to have been published on this subject. Some information relative to proper methods of the restoration of electrode coatings would also be valuable.[145] As study of this sort should include all types of commercial electrode coatings.[145]

The cause of hot-cracking, associated with the presence of iron sulphide, should be further investigated. Why should low-hydrogen electrodes be more successful in avoiding hot-cracking in the welding of sulphur steels?[147] There is certainly some evidence that carbon, silicon and hydrogen can play some part in the phenomenon.[147]

The role of hydrogen in the formation of porosity is also not yet understood.

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Brazing Hydromechanics

Factors affecting the rate of completion of a brazed joint are related to the physical constants of the brazed metal, its surface tension and joint dimensions

by E. R. Funk and H. Udin

Abstract

In this paper the factors affecting the rate of completion of a brazed joint are studied by the application of the elementary laws of hydromechanics. Equations are derived which relate the physical constants of the brazed metal, its surface tension, and joint dimensions to the interface velocity of both vertical and horizontal joints. In addition a study is presented of flow through the two types of capillary dams. These considerations have been modified to include the more practical case of fluxed joints. Finally we have highlighted the ramifications on design for brazing of the principles introduced here.

INTRODUCTION

BRAZING differs from welding in that filler materials having a melting point below that of the base metal are used for making a joint without melting the parent metal. Many techniques may be employed to bring the assembly to a temperature at which the brazing alloy is molten. But in all true brazing operations, as distinguished from braze welding, the liquid filler metal spreads until the volume between the parts to be joined is filled. An analysis of the conditions which lead to spreading and filling have been discussed elsewhere. In this paper we shall pursue the problem one step further and study the factors affecting the rate of completion of a brazed joint.

Hydromechanists have studied the characteristics of liquids flowing smoothly when confined by ducts or pipes. In its simplest form the brazing operation is quite analogous to the case of water moving through a duct since it consists of a liquid moving between two flat solid surfaces. The force moving the brazing alloy is much more subtle than the pump or pressure head acting upon the water and for this reason some attention should be devoted to the driving force behind brazing.

THE HORIZONTAL BRAZED JOINT

A cross section of a horizontal lap joint being brazed is shown in Fig. 1. An enlarged view of the advancing front of brazing compound is presented in Fig. 2. The fact that this advancing front is curved rather than flat is of greatest significance to us and does, as will be seen shortly, actually lead to the driving force. This curved surface, or meniscus, is a direct result of the surface tension of the liquid.

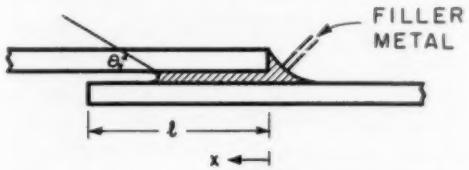

Fig. 1 The cross section of a horizontal brazed joint

Mathematically, the pressure driving the brazing liquid between the plates can be related to the surface tension of the liquid by

$$\Delta P = \frac{-2\gamma \cos \theta}{D} \qquad (1)$$

where γ is the surface tension of the filler alloy. θ is called the *contact angle*.

Equation 1 is a special case of a more generalized equation

$$\Delta P = -\gamma \left(\frac{1}{R_1} + \frac{1}{R_2} \right)$$

where ΔP is the pressure across an interface, and R_1 and R_2 are the principle inverse curvatures of the interface. γ is the excess energy residing at the interface, or the interfacial tension. This equation may be derived in the following manner.[1]

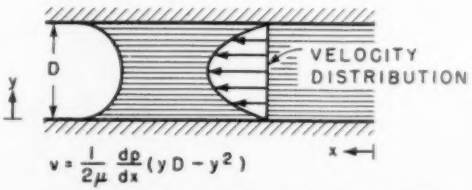

Fig. 2 The velocity distribution in laminar flow

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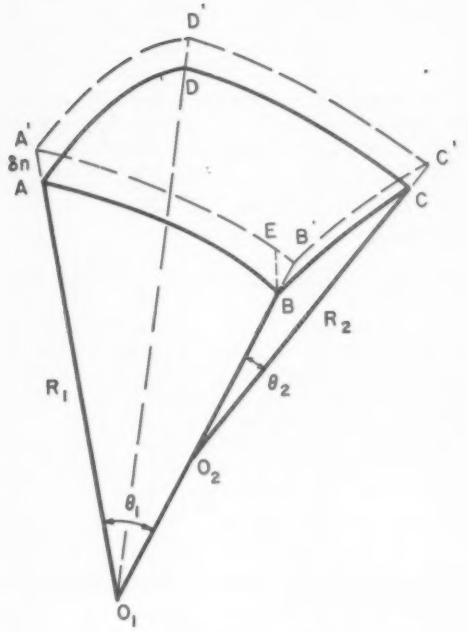

Fig. 3 A curved liquid surface

Consider the curved surface $ABCD$ in Fig. 3 whose sides are at right angles. Let this area be displaced parallel to itself, away from the concave side, by a distance δn, with the normals to the boundaries in the displaced position $A'B'C'D'$ the same as the normals in the original position. The normals at A and B meet at O_1. Those at B and C at O_2. Let the radius of curvature of the arc AB be R_1 and that of BC be R_2. The angle AO_1B is AB/R_1 radians and BO_2C is BC/R_2. The area of the element of surface after the displacement is

$$\left(AB + \frac{AB}{R_1}\,\delta n\right)\left(BC + \frac{BC}{R_2}\,\delta n\right)$$

Neglecting second order quantities this becomes

$$ABCD\left(1 + \frac{\delta n}{R_1} + \frac{\delta n}{R_2}\right)$$

The work done in increasing the area against the free energy or surface tension γ of the surface is therefore

$$\gamma\, ABCD\,\delta n\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

This work is supplied by the pressure difference across the curved surface. If the pressure of the concave side is P_1 and on the convex side is P_2, the work done by this pressure difference is

$$(P_1 - P_2)\,\delta n\, ABCD$$

Since no work is done by any other forces, the work of the increased area is equal to the work done by the pressure difference.

$$(P_1 - P_2) = \Delta P = \gamma\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

For closely spaced flat plates the curvature along the meniscus is zero ($R_2 = \infty$), and the curvature of the meniscus is $D/2 \cos\theta$. For perfect wetting, as in Fig. 2, $\cos\theta$ equals unity, and the pressure across the surface reduces to

$$\Delta P = -\frac{2\gamma}{D} \tag{2}$$

The rate of advance of this column can now be considered. Under the conditions of brazing it is warranted to consider that laminar flow of the alloy occurs. The theory and equations of laminar flow are well known. Pure laminar flow between flats leads to a non-linear velocity distribution as shown in Fig. 2. The velocity v at any point y between the surfaces is

$$v = \frac{1}{2\mu}\frac{dp}{dx}\,(y^2 - yD) \tag{3}$$

where μ is the viscosity and D is the distance between flats. The average velocity $\bar{v}$ can readily be shown to be

$$\bar{v} = -\frac{1}{12\mu}\left(\frac{dp}{dx}\right)D^2 \tag{4}$$

It now remains to relate the driving force ΔP from Equation 2 to the velocity through Equation 4. For a uniform spacing (dp/dx) is actually $\dfrac{\Delta P}{x}$ so that Equation 4 may be written as

$$\bar{v} = -\frac{1}{12\mu}\,D^2\,\frac{\Delta P}{x} \tag{5}$$

Now substituting (2) into (5) we obtain the velocity of the advancing film of liquid

$$\bar{v} = \frac{1}{6}\,\frac{\gamma D}{\mu x} \tag{6}$$

Now that the rate of motion is known, the time t for flowing a distance x can be found by simple integration.

$$t = \int \frac{dx}{\bar{v}} \tag{7}$$

$$t = \frac{3\mu x^2}{\gamma D} \tag{8}$$

And from this we can readily write the distance flowed in any length of time.

$$x = \sqrt{\frac{\gamma D}{3\mu}\,t} \tag{9}$$

Thus, the distance flowed is related to the physical properties of the brazing alloy, the plate separation and the time allowed for filling. From the form of Equation 9 it is evident that a high γ/μ ratio is desirable for brazing compounds. It is well known that a compound of low viscosity (high fluidity) leads to more complete filling and better brazed joints. The possibilities for increasing the γ/μ ratio lie primarily with decreasing

the viscosity. Increasing the surface tension above the highest value possessed by any element in the brazing alloy appears to be thermodynamically impossible. Nevertheless, contrary to most statements in the brazing literature, the highest surface tension compatible with complete or nearly complete wetting is always to be desired.

At first glance it is strange that the temperature should not be included as a variable in Equation 9. Surely a higher temperature does promote a faster joint. And this is so because the γ/μ ratio increases quite rapidly with temperature. For all practical purposes γ is independent of temperature while the viscosity μ decreases exponentially with temperature, thus leading to an increasing γ/μ with temperature.

Two conclusions are of interest concerning the relationship of time and distance. First, it can be seen that doubling the time at brazing temperature does not double the distance flowed but instead only multiplies the original distance by 1.4. Second, there is no limit to the distance which can be covered as long as an adequate supply of filler metal is available. But, of course, a practical limit is soon reached where the return for longer times in terms of distance flowed is not sufficient.

While there is no theoretical limit to the distance the brazing alloy may flow between horizontal flats, there is a limit to its flow in the next case we shall consider. Often brazed joints are designed so that the brazing compound is drawn vertically up between two plates. As a matter of fact, this is the preferred way for filling a brazed joint when it is essential that no air pockets be trapped. An analysis of this case is presented in the following section.

THE VERTICAL BRAZED JOINT

In the vertical brazed joint the liquid column moves upward in response to the same capillary pressure ΔP but now a second factor enters which opposes the rising of the column. The liquid column, of course, has weight, so that the higher it goes, the larger becomes the weight of the column that must be supported by the differential pressure. In this case then

$$\Delta P = -\frac{2\gamma}{D} + (\rho - \rho')gh \qquad (10)$$

where $(\rho - \rho')$ is the density of the brazing liquid minus the density of surrounding medium. When the surrounding medium is gaseous, ρ' is much less than ρ and so may be neglected. h is the vertical distance above the level of the liquid pool.

The rate at which this column moves upward is again controlled by the equation of fully developed laminar flow. Since the flow is vertical rather than horizontal, Equation 3 should be rewritten to conform to the convention for the x and y axis,

$$v = \frac{1}{2\mu}\frac{dP}{dy}(x^2 - xD) \qquad (11)$$

And the average velocity in the y direction is

$$\bar{v} = -\frac{1}{12\mu}\left(\frac{dP}{dy}\right)D^2 \qquad (12)$$

The driving force ΔP is given in Equation 10. Noting that dp/dy is actually $(\Delta P/y)$, the average velocity at any point y as the column moves upward is

$$\bar{v} = \left[\frac{D\gamma}{6\mu y} - \frac{D^2\rho g}{12\mu}\right] \qquad (13)$$

And the time to reach a height y is

$$t = \frac{12\mu}{D^2\rho^2 g^2}\left[-D\rho g y - 2\gamma \log_e\left(\frac{(2\gamma - D\rho g y)}{2\gamma}\right)\right] \qquad (14)$$

One of the most evident differences between the horizontal and vertical case is in the limit of the distance flowed. While there is theoretically no limit to the distance the compound can flow in the horizontal case, there is a definite limit in the vertical case. This limit comes when the driving force ΔP disappears under the weight of the column it is supporting. So that here $\Delta P = 0$; and from Equation 10

$$\Delta P = 0 = \frac{2\gamma}{D} - \rho g y_{max.} \qquad (15)$$

From this equation we get the familiar equation for the capillary rise,

$$y_{max.} = \frac{2\gamma}{\rho g D} \qquad (16)$$

Equation 14 can be simplified by expressing the amount of filling in time, t, as a ratio of the distance flowed over the maximum obtainable height, y max, so that

$$R = y/y_{max.} \qquad (17)$$

From which Equation 14 becomes

$$t = \frac{12\mu\gamma}{\rho^2 g^2 D^2}\left[-2R - 2\log_e(1 - R)\right] \qquad (18)$$

Equation 18 is somewhat more complicated than the time-distance relationship for the horizontal case. (Equation 8). This added complication in the vertical case is the result of the fact that the higher the column rises the greater the weight of the column in motion becomes.

COMPARISON OF VERTICAL AND HORIZONTAL BRAZED JOINTS

Since many brazed joints are made in the vertical position, it is of interest to see what advantage might be gained in making these joints in the horizontal position. To answer this question let us refer to Fig. 4. Here the time for the flow to a distance specified in terms of the highest possible vertical rise is compared for the two cases. This curve really compares the time it takes to fill a joint in the vertical position with the time it takes to fill the same joint in the horizontal position. From the shape of the two curves it is apparent that as long as the joint length is not too close to the maximum obtainable in the vertical position, the time for

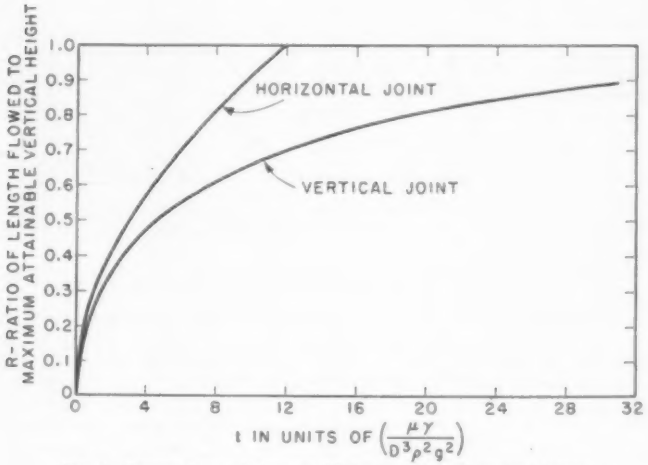

Fig. 4 Comparison of time to fill horizontal and vertical joints

filling a vertical joint is not appreciably longer than the time for filling the joint horizontally.

It will be helpful to have some idea about the magnitude of the maximum obtainable height in a hypothetical joint using pure copper on iron. For such a case $\gamma = 1100$ dynes/centimeter, $\rho = 8.94$ grams/cc.,[3] $g = 980$ cms./sec.[2] Taking $D = 0.005$ in. $= 0.013$ cm., we obtain from Equation 16

$$y_{max.} = \frac{2(1100)}{(8.94)\ (980)\ (0.013)}$$

$$y_{max.} = 1.95 \text{ centimeters} \sim {}^3/_4 \text{ inch}$$

We can now see from Fig. 4 that a half inch joint would be consummated about 50% faster in the horizontal position than in the vertical position. A larger joint would show a considerably greater saving in time. One must bear in mind, however, that these comparisons are for a joint thickness of 5 mils. A smaller joint thickness will lead to much less time saving; thus a 2 mil. joint one half inch long gives a differential of only about 8%. It is clear that the advantages of vertical brazing in minimizing gas entrapment far outweigh the economy of time in horizontal brazing.

It will be interesting to compute the time required to complete a half inch lap joint of 5 mil. thickness. Again, assume the simple cases of iron being brazed with pure copper. This is necessary since the surface tension and viscosity values for other brazing alloys are not available. It is, therefore, difficult to get a realistic picture of actual brazing conditions but it is felt that the copper braze on pure iron is not in greater error. The best obtainable values of μ, γ may be put into Equation 8 to give

$$t = \frac{3\mu x^2}{\gamma D} = \frac{3(3.41)(1.2)^2}{(1100)(0.012)}$$

$$t = 1.1 \text{ seconds}$$

where μ_{copper} is 3.41 centipoises at 1145° C. and γ is taken as 1100 dynes/centimeter. The surface tension here is the surface tension of liquid copper saturated with iron. No actual figures for this are in the literature, however, the work of Van Vlack[2] makes 1100 dynes per centimeter not an unreasonable estimate.

Under actual brazing conditions a flux is always present. Fluxing is necessary to promote a clean and efficient joint. In this case the plate as well as the brazing compound are in chemical equilibrium with the flux. The mathematics of this more realistic case is unchanged but the values of μ and γ for the brazing compounds are affected. γ, which is actually the interfacial tension between the liquid metal and the atmosphere, becomes, in the presence of flux, the interfacial tension between the liquid metal saturated with flux and the liquid flux itself. This condition makes it desirable for the surface tension of the liquid flux to be low. However, a minimum value for the surface tension of liquid flux is not necessarily the condition for maximum interfacial tension.

There are techniques for measuring the interfacial tension between the liquid metal and the flux but no measurements have been made and published. The nearest approach made so far is the work of Van Vlack[2] on liquid copper/copper sulfide interfaces. Further work in this field would contribute to the theory and practice of brazing.

IMPEDED FLOW—CAPILLARY DAMS

Up to this point we have considered the relationships of time, distance and physical properties involved in filling a lap joint with a brazing liquid. Although we have considered two cases, the horizontal and the vertical joint, in both the assumptions has been made that the plates to be brazed were perfectly flat. In practice this condition seldom is found since tool marks or peculiarities of joint design obstruct the free flow of the liquid. Obstructions caused by a change in cross section of the capillary tube we shall call capillary dams. There are two kinds of capillary dams, one in which the cross section becomes larger for a short distance and the other in which the cross section becomes smaller or constricted.

We shall consider schematic examples of the two types of capillary dams. Figure 5 is a dam in which the cross section expands uniformly from D to $(n + 1)D$. Consider first the horizontal position as shown in Fig. 5. As the dam begins to fill, the pressure driving the liquid reduces as the radius of curvature increases in accordance with Equation 2. In addition more liquid is required to fill the dam than would be required to fill an equivalent length of uniformly narrow gap. These two

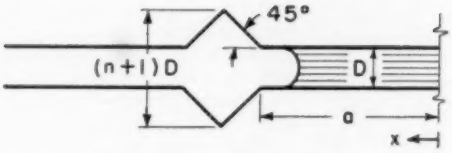

Fig. 5 A dilated capillary dam

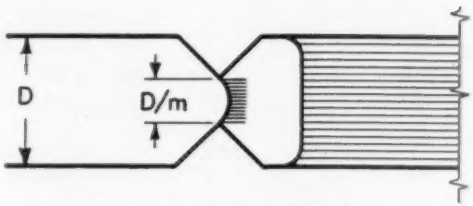

Fig. 6 A constricted capillary dam

conditions superimpose to slow the rate of flow in the constriction. However, once the dam is filled, the brazing compound moves on unaffected by the capillary dam.

The analysis is somewhat cumbersome so that only the results will be given here. The time to fill past a dam which is a distance "a" from the beginning of the joint and size $(n + 1)D$ is given by

$$t = \frac{6\mu an}{\gamma}\left(1 + \frac{n}{2}\right) + \frac{3\mu a^2}{\gamma D} \qquad (19)$$

The viscous drag within the groove has been neglected in the derivation. If this drag is included the resulting equation is unwieldy but upon evaluation it is not appreciably different from Equation 19 as long as "a" is large compared to D.

Let the dam be simply a gouge of depth D on each face so that $n = 2$. If this dam is $^1/_4$ inch from the edge, and the joint is 0.005 in. thick, then it will take about thirty times as long to fill past the dam as it would if no dam were encountered. We have seen that the time to fill such a joint is surprisingly short, i.e., about 0.3 seconds, so that small tool gouges may have an appreciable effect.

If a dam of this nature occurred in a vertical joint there is the likelihood that it would permanently stop the flow upward. It can be seen from Equation 16 that the maximum obtainable height is inversely proportional to the radius of curvature. This means that as n increases the maximum obtainable height decreases. An advancing front will be permanently stopped when the gouge occurs between $y_{max.}$, the undammed maximum height and $y_{max.}/(n + 1.)$ For the vertical joint then, a gouge in each plate of depth D will stop the flow if the gouge is more than one third Y max. up the plate. Such a dam becomes very effective in the vertical joint while remaining relatively innocuous in the horizontal lap joint.

The other kind of dam is a constriction in the capillary. Consider such an idealized constriction as shown in Fig. 6. Although the radius of curvature increases in this dam, resulting in rapid movement through it, the flow of the liquid past it is cut down just as an orifice decreases flow in a pipe. Of course, in the limit the constriction completely closes the pipe and no further flow is possible.

It is common practice to express the flow retarding characteristics of an orifice in terms of the number of drameters the orifice effectively adds to the system's length beyond the orifice. Using this convention, it can be shown that the effective increase in length is $\frac{m^2-1}{2}$D. In order to noticeably affect the speed of brazing, the m must become quite large. m is a measure of the constriction effect as shown in Fig. 6. For example, on a 0.005 inch joint, a gap as small as 0.001 inch would increase the effective length of the joint by only $12D$ or 0.060 inch. Of course, if the gap became very tiny, say 0.0001 inch, then the rate of flow past this constriction is so slow that for practical purposes the joint could not be consummated.

If the constricting dam occurred in a vertical joint there would be no effect at all on the maximum obtainable height. The time to obtain a joint would be effected in much the same way as the horizontal joint—that is, very little retarding until the gap becomes much smaller than the joint dimension.

The analysis of capillary dams shows that a change in dimension of the joint can have a pronounced effect in some cases while in others this effect is negligible. Thus a groove in the plates may permanently retard a vertical joint while the same groove in a horizontal joint temporarily slows the advancing brazing alloy. A constriction in either case is relatively innocuous until the gap becomes almost closed. These generalizations can lead to considerations of some importance in the design of brazed joints.

THE EFFECT OF A FLUX

In practice it is difficult to achieve a satisfactory brazed connection without the use of a flux. A flux is a chemical agent, generally a metal halide or borate, which aids the brazing operation by dissolving the oxides which have formed on the metal surfaces. It also coats the cleaned surface to prevent further oxidation. Handbooks often state that flux lowers the surface tension of the filler metal and thereby speeds brazing. It is highly questionable that the flux does actually affect the surface tension of the liquid metal since the solubility of flux in metal is very low. Only experiments in which the surface tension is measured in the presence of flux can prove how the flux affects the liquid surface tension. But in any case we have seen that a large value of braze metal surface tension is desirable.

The influence of flux in a joint being brazed can be examined analytically. Let us take the simplest case of the horizontal joint as shown in Fig. 7. Here the braz-

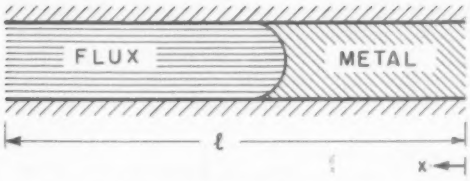

Fig. 7 A slag-metal interface in a horizontal joint

ing alloy must displace the flux by pushing it out of the joint. In this case, then, the driving force is overcoming the flow resistance of the flux as well as the liquid metal. The velocity with which the slag-metal interface moves in the horizontal joint is

$$v = -\frac{D^2}{12}\left[\frac{\Delta P}{x\mu_m + (l-x)\mu_s}\right] \quad (20)$$

$$v = -\frac{D^2}{12}\Delta P\left[\frac{1}{x(\mu_m - \mu_s) + \mu_s l}\right] \quad (21)$$

As before, the time to fill to any point is

$$t = \int \frac{dx}{v} = -\frac{6x^2}{D^2\Delta P}(\mu_m - \mu_s) - \frac{12\mu_s l_x}{D^2\Delta P} \quad (22)$$

$$\Delta P = \frac{-2\gamma_i}{D}$$

where γ_i is the interfacial tension between slag and liquid metal. Only experiment can tell us the value of this interfacial tension and it is unfortunate from this point of view that it can not correctly be equated to the difference of γ_{metal} and γ_{slag}. An experiment must be performed in which the surface tension of the metal is measured while in equilibrium with the slag. We can suppose that the presence of the slag will not greatly diminish the γ_{metal}, and it is desirable for efficient brazing that γ_i be close to γ_{metal}.

The pronounced effect of the flux under various conditions can be seen by examining Equation 22 under three cases.

1. When μ_s is very small compared to μ_{metal}. Here

$$t = -\frac{6x^2}{D^2\Delta P}\mu_m \quad (23)$$

and with $\Delta P = -\frac{2\gamma_i}{D}$

$$t = \frac{3}{2}\frac{x^2\mu_m}{D\gamma_i} \quad (24)$$

This result is very similar to the result in the previous section in which the slag was neglected. As before the flow begins very rapidly and slows with increased distance covered.

2. When μ_s is much larger than μ metal, then

$$t = -\frac{12\mu_s}{D^2\Delta P}\left(lx - \frac{x^2}{2}\right) \quad (25)$$

$$t = \frac{6\mu_s}{D\gamma_i}\left[x\left(l - \frac{x}{2}\right)\right] \quad (26)$$

It can be seen from Equation 21 that in this case the velocity is slow and characteristic of the slag at the beginning of filling but increases as the joint is completed.

3. When μ_s and μ_{metal} are approximately equal, the time becomes simply

$$t = -\frac{12\mu_s lx}{D^2\Delta P} \quad (27)$$

$$t = \frac{6\mu_s l}{D\gamma_i}x \quad (28)$$

The rate of movement of the interface for this case is constant. Although the vertical joints may be similarly treated, the conclusions reached here may be applied remembering that the maximum attainable height is influenced by the density of the flux. In the non-fluxed case we were able to neglect the density of the surrounding medium.

CONCLUSIONS

In the design of the brazed joints attention to clearance is necessary. An abrupt change in clearance leads to capillary dams which impede the flow of the brazing compounds. The degree of impedance depends on the location of the dam, its shape and size and the attitude of the joint. Two examples of bad joint design should be mentioned.

Consider a rounded washer placed on a right angle such as shown in Fig. 8. The wide clearance at the fillet will slow or possibly stop altogether the flow of brazing compound into the joint.

On the other hand, a square cross section washer on a rounded angle as shown in Fig. 9 will limit the flow of brazing liquid. Two general rules might be stated for the design of brazed joints as a result of the study of dams. First, keep joint clearance uniform throughout and second, avoid line contacts of the parts to be joined.

For short joints, the time for filling a vertical joint is only slightly longer than the time for completing a horizontal joint of the same length.

It is well known that the surface preparation is important in brazing. A poor surface finish will hinder or completely stop the filling due to the presence of many capillary dams of varying characteristics. The finer the finish the less the impedance to flow. It might also be noted that the final surface scratches or tool marks are far less detrimental if they run in the direction of the metal flow rather than perpendicular to it. As a matter of fact, if the contact angle between base and filler metals is greater than zero, fine scratches in

Fig. 8 A rounded washer on a square tee

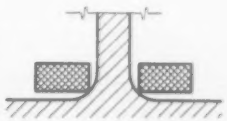

Fig. 9 A square washer on a rounded tee

the direction of the joint will actually speed the filling.[2] Other than these effects, surface finish has little influence on the rate of filling, since the boundary velocity of laminar flow is zero, regardless of surface condition.

In the consideration of the brazing alloy and flux, it has been seen that an alloy of high surface tension or high slag-metal interfacial tension is desirable consistent with the surface energy requirements of wetting. More rapid filling is obtained when both the slag and the molten metal have low viscosities.

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A Résumé of the Ship Fracture Problem

The work of the Ship Structure Committee has led to major improvements in existing ships and points the way for better steels, fabricating procedures and design in new construction

by Finn Jonassen

THE Ship Structure Committee* represents a combined effort of its member agencies to improve the hull structure of ships by an extension of knowledge through research in the fields of design, materials and methods of fabrication. The following agencies have membership in the Ship Structure Committee:

Bureau of Ships, Department of Navy
Military Sea Transportation Service, Department of Navy
United States Coast Guard, Treasury Department
Maritime Administration, Department of Commerce
American Bureau of Shipping

Thus through the Ship Structure Committee technical and financial resources of both Government and regulatory agencies are pooled and brought to bear on the solution of structural problems of ships' hulls.

An extensive study to determine the underlying causes of structural failures such as those recently sustained by the tankers *Fort Mercer* and the *Pendleton* has been in process for the past several years sponsored first by the Board to Investigate the Design and Methods of Construction of Welded Steel Merchant Vessels,† and now by the Ship Structure Committee.

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The opinions expressed in this paper are those of the author and do not necessarily represent those of the committees of the NAS-NRC or of the Ship Structure Committee.

* First Technical Progress Report of the Ship Structure Committee. Mar. 1, 1948; THE WELDING JOURNAL **27** (7), Research Suppl., 377-s to 384-s (1948). Second Technical Progress Report of the Ship Structure Committee, July 1, 1950; THE WELDING JOURNAL, **30** (4), Research Suppl., 169-s to 181-s (1951).

† Final Report of a Board of Investigation to Inquire into the Design and Methods of Construction of Welded Steel Merchant Vessels, July 15, 1946; THE WELDING JOURNAL, **26** (7), 569-619 (1947).

Many research investigations have been carried out in outstanding engineering laboratories in the United States under the guidance of advisory committees of the National Academy of Sciences-National Research Council. Academy-Council advisory committees have continuously assisted the Board and the Ship Structure Committee in planning, organizing and maintaining research programs related to the problem of brittle failure of ships. This work requires substantial funds for its prosecution but it is noteworthy that the cost of the research program to date only approaches the cost of replacement of one broken ship.

The problem of brittle failure is very involved, and in spite of its extensive history, it is far from understood. However, as an outcome of the research program sponsored by the Board and the Ship Structure Committee, much light has been thrown on the brittle fracture problem, such as a better understanding of the role of the notch bar test and the importance of temperature in separating ductile and brittle behavior.

An analysis of ship failures indicates that their causes may be attributed to deficiencies of design, fabrication and materials.* In consequence, the research program undertaken has been directed toward achieving solutions in these fields.

Many improvements have been made in the design of structural details of the ship's hull. Fabrication techniques have also been improved thereby reducing the number of defective welds present in ship's hulls. The effectiveness of these changes is demonstrated by the significant reduction of ship failures as compared to the number that occurred during the first several years of welded ship fabrication. Further design

* It has been determined that the steel used in the construction of welded ships met specifications in force at the time.

improvements can undoubtedly be made particularly as a result of the structural research program sponsored by the Committee.

Fractures, however, continue to occur originating even at extremely minor details which would be impossible to eliminate entirely under practical shipbuilding conditions. In addition, operational practices can and do result in establishing minor defects which could provide the source of failures. An outstanding example of a major failure originating at a minor defect is the breaking in two of the tanker *S.S. Ponagansett*. (This ship broke in two while tied at an outfitting pier in Boston, Mass., December 1947.) Here the fracture originated at a fabrication detail which neither good design nor fabrication procedure would condemn as being improper. Such failures can only be eliminated by the use of steel which is tolerant of such minor defects, i.e., a steel which is crack resistant or notch tough.

That real structural improvement can be obtained upon the use of notch tough steels has been amply demonstrated through the research program conducted by the Ship Structure Committee. Thus the over-all resistance of a ship to resist cracking is increased by the use of more notch tough steel. Specifying killed steel is known to be effective in increasing notch toughness and thereby reducing the tendency to crack. Further improvements are possible by reduced carbon content and increased manganese content, by specifying fine grain practice and by normalizing. Some of these improvements to obtain more crack-resistant materials have already been specified (in 1948) by the American Bureau of Shipping, a member agency of the Ship Structure Committee, for steel to be used in new construction and for repairs.

However, whether the refinements in design, improved quality of fabrication and the use of a generally more notch tough steel incorporated in welded ships built during the past several years are sufficient to prevent structural failures remains to be demonstrated. So far, no major fractures have occurred in this group of ships.

Ultimately, in order to have the highest assurance that steels meet required standards of notch toughness, the use of a notch bar test will undoubtedly have to be specified. This is presently not feasible because there is no general agreement as to the choice of specimen and also there is not sufficient knowledge regarding the level of performance required in any one notch bar test to give the necessary assurance that the steel will perform satisfactorily for welded ships.

Since it is not known whether the present requirements for the construction of welded ships are sufficient to prevent structural failures, it may be well to consider further improvements to increase the crack resistance of ships. A number of such improvements are known and they can be instituted now in spite of lack of knowledge of quantitative requirements for notch toughness. Some of these are:

1. Normalizing, particularly for the heavier plate thickness.
2. Reducing the strength requirement of shipbuilding steel by lowering carbon content. Such a change will produce a tougher and more weldable steel.
3. Specifying the use of only killed steel for the midlength of the ship or at least for the known critical areas of this portion of the ship. As mentioned earlier, additional improvements of steel quality result from the use of reduced carbon and increased manganese content, fine grain practice and normalizing.
4. Requiring subsurface inspection of welds at least of welded butts in critical areas of the ship.
5. Specifying the use of low-hydrogen electrodes.
6. Modifying designs to reduce scantlings thereby reducing plate thickness wherever possible will also add to the notch toughness of the structure.
7. Eliminating bulb shapes since sound butt welds are difficult to make in these shapes.

The improvements proposed above cannot, of course, be applied to existing vessels; however, remedial measures have been devised for ships in this category. These consist of riveted crack arrestors which represent the best solution now available for the protection of large all-welded steel structures. These crack arrestors have proven effective in halting a number of fractures thereby undoubtedly preventing some ships from breaking in two. If, however, the load on the hull is sufficiently high, it is of course realized that these crack arrestors cannot maintain the integrity of the structure, particularly when the fractures have become extensive. It is noted that ships fitted with crack arrestors have broken in two.

Other remedial measures to existing ships are proposed. These emphasized modification and procedures to minimize the initiation of fracture. Some of these are:

(*a*) Regulate loading to reduce bending stresses in a seaway. This is particularly emphasized in the case of tankers.

(*b*) Omit bilge keels to eliminate this source of fracture; or alter bilge keels by tapering ends, eliminating cut-outs, riveting butt joints or other alterations to reduce likelihood of cracks originating in this area.

(*c*) Increase the longitudinal strength of tankers. This modification will lower nominal bending stresses in the hull and thereby reduce the effect of stress raisers such as at interrupted bottom longitudinals and at weld defects in welded butts.

(*d*) Inspect extensively strength welds in critical portions of the hull girder utilizing available methods for subsurface examination. The inspection should be directed particularly to

the bottomshell butts in tankers and to the deck butts in dry cargo ships.

The early importance attached to residual welding stresses and locked-in stresses, particularly as they might affect structural performance, directed the first research efforts to investigate these factors. An extensive research program on full-scale weldments and on ships has yielded a large amount of information on the magnitude and distribution of these stresses but no direct evidence has been found to indicate that these stresses are important in causing fractures in welded ships.

It might appear that a return to riveting would be the solution of this problem. There are many advantages inherent in the all-welded ship that cannot be realized by riveting and which are translatable into savings in construction and operating costs. Some of these are:

(*a*) Speed of construction. This is particularly important in the event of a "national emergency."

(*b*) Tightness of hull and tanks which is easy with welding—difficult with riveting.

(*c*) Weight saving, resulting in greater cargo carrying capacity.

(*d*) A smoother hull with consequently lower resistance, hence more speed with the same power.

(*e*) The ease with which qualified welding operators can be trained as compared with riveters; utilization of women as welders.

In consequence, a return to riveted construction is considered economically undesirable in time of peace and may be impossible in time of war since facilities for the construction of riveted ships cannot be quickly expanded.

The aims of the research program sponsored and financed by the Ship Structure Committee may be summarized as follows:

(*a*) To resolve the present cracking problems of the welded ship so that ultimately *all*-welded ships with their many advantages can be constructed and operated anywhere in the world without danger of structural failure. Thus the lives of the passengers and the crews of such vessels will not be jeopardized by hazards of structural failure in addition to those of the natural forces of nature to which ships are normally exposed.

(*b*) To improve design, fabrication techniques and materials with the view of simplifying construction practices and to reduce construction costs.

Incorporating the recommendations contained herein will undoubtedly add to the cost of ship construction. This additional burden represents then a further handicap which the American Merchant Marine will have to overcome in its competition with merchant fleets of other nations. However, the American Merchant Marine is already operating under very serious disadvantages resulting from the uncontrolled cracking and breaking in two of tankers and cargo vessels and, in particular, from the loss of life associated with these ship failures. The replacement cost of one lost ship will defray the extras necessary for the purchase of large amounts of more notch-tough shipbuilding steel.

The Suitability of Various Steels for Flash Welding

by Erick Hormann

SUMMARY

FLASH welding is suitable for a wide variety of plain carbon and alloy steels, if welding conditions are correct and if, where required, the welded joint is heat treated. The only steels not suitable are steels containing high silicon and particularly aluminum. To avoid cracks, especially close to the weld the joint should not get too hot. If grain boundaries open up close to the weld, the push-up pressure should be raised and the welding time shortened. Heavy sections and thick walls require preheat. Push up pressures of 2800 to 4200 psi. are sufficient for plain carbon steel, but 8500 psi. is recommended for alloy steels. High-alloy chromium-nickel steels require still higher pressure and additional preheat.

Flash welding gives such good results that it is widely used with fully automatic machines for creep-resistant superheater steels (up to 1100° F.) and for steels resistant to high-pressure hydrogen in hydrogenation plants. Other applications are rails, motor housings of chromium-vanadium steel, connecting rods and three-blade propeller hubs. The hub is forged in halves which are flash welded together. Crankshafts and locomotive valve rods also are flash welded.

Carbon content does not affect flash welding as it does arc welding, so that high-carbon steels are flash

Abstract of "Die Eignung von Stahlen fur das Abbrennstumpfschweissen," published in Stahl u. Eisen, 72, 19–24 (1952). (Abstracted by Dr. G. E. Claussen.)

welded readily. As the silicon content is increased the weldability decreases, until with 1.5% silicon the steel becomes unweldable even in a protective atmosphere. A high aluminum content intensifies the bad effect of silicon. Chromium steels usually are welded in a protective atmosphere, such as a hydrogen flame to avoid oxide films. In some cases briquettes of brown coal mixed with a hydrogen-consuming substance such as ammonium chloride, are placed inside the pipe. The burning of the coal removes oxygen from the vicinity of the weld and helps prevent the formation of oxide films.

Molybdenum and chromium-molybdenum steels are easy to weld with sufficient pressure and protective atmosphere. If welding conditions are closely controlled with respect to preheat and pressure, protective atmospheres need not be necessary for chromium-vanadium steels, which may require special heat treatment after welding.

In view of their different properties, high-alloy nickel and chromium-nickel steels require higher preheat and pressure. Tantalum and columbium in these steels do not change the welding behavior. Titanium in plain carbon and 16% Cr steels does not affect weldability.

Tests to determine the effect of push-up pressure are summarized in Fig. 1 for pipes 9 in. O.D. of steel containing 0.10 C, 0.19 Si, 0.46 Mn, 6.04 Cr, 0.84 Mo, which had been heated after welding 30 min. at 1750° F. and 1 hr. at 1380° F. with air cooling. The decarburized zone became narrower as the pressure increased. The tensile specimens without cross hatching in Fig. 1 broke in the weld; the shaded specimens broke outside the weld. The lightly shaded bend results in Fig. 1 had porosity or small openings in the weld; the heavily shaded specimens did not. The best results were obtained at 11,400 and 14,200 psi.

As an illustration of the uniformity of welding obtainable with a fully automatic Siemens-Schuckert flash welder, reference may be made to tests on different sizes of pipes with 0.175 C, 2.83 Cr, 0.45 Mo, 0.37 W, annealed at 1300° F. for 2½ hr. after welding. Every weld was examined externally either by grinding and etching or by filing at 45 degrees to the weld. Unsound areas, porosity and inclusions are revealed by these methods. When defects were found, bend specimens of the defective weld revealed oxide films and unsound areas in the fracture. Since only 1 to 2% of the welds failed in this careful program of examination, it was concluded that welding was surprisingly good. For pipes 3 in. O.D., 0.57-in. wall (4.4 sq. in.) the welding time was between 90 and 99 seconds, the push up between 0.33 and 0.37 in.

In tests on pipes 6¾ in. O.D. 1.57-in. wall (26 sq. in.) containing 0.17 C, 3.3 Cr, 0.52 Mo, 0.93 V, 0.4 W welded with 8500 psi. pressure and heat treated after welding (2 hr. at 1900° F., air-cooled, then 2 hr. at 1380° F., air-cooled) very low bend angles were obtained at first although no oxide films were seen in the fracture. There was a decarburized zone 0.08 in. wide at the weld, but spectrographic tests showed only trifling losses of Mn, Mo and Cr, and none of W or V. The Brinell was 60 units low in this zone. However, after an additional 2 hr. anneal at 1750° F. the bend specimens could be bent 180° without cracking. The specimens were 1.18 in. wide, 1.57 in. thick. The additional heat treatment still did not equalize the hardness.

Small superheater tubes containing 0.18 C, 1.6 Cr, 0.45 Mo, 0.35 V gave excellent bend values when welded under controlled conditions and heat treated 2½ hr. at 1330–1350°F., cooled in the furnace to 1110°F. and then cooled in air.

Tensile bars from welded pipes containing 0.46 Cr 1.63 Cr gave strenghts of 128,000–135,000 psi, and 180 degree bend angles without cracks. Similar results could be obtained with steel containing 0.37 C, 1.54 C-if welding conditions were selected properly. However, very low bend angles were obtained without protective atmosphere and without automatic postheating; in other words, the current was shut off as soon as pressure was applied. Fractures close to the weld occurred in these tests. This type of fracture will be discussed later.

Bend specimens of welded pipes with 0.70 C, 0.80 Mn with the outside of the pipe in tension could be bent

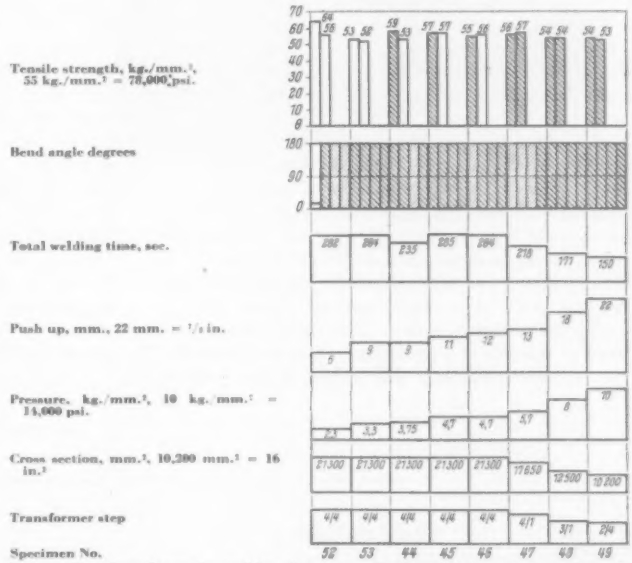
Tensile strength, kg./mm.², 55 kg./mm.² = 78,000 psi.
Bend angle degrees
Total welding time, sec.
Push up, mm., 22 mm. = ⅞ in.
Pressure, kg./mm.², 10 kg./mm.² = 14,000 psi.
Cross section, mm.², 10,200 mm.² = 16 in.²
Transformer step
Specimen No.
52 53 44 45 46 47 48 49

Fig. 1 Results of tensile and bend tests on flash-welded specimens from 9-in. tubes containing 6% Cr, 0.8% Mo

180° without cracking, but only 30 to 40° with the inside of the pipe in tension. In the latter case fracture occurred close to the weld at clusters of manganese sulphide inclusions on the inner wall which were upset by welding.

Numerous tests on centrifugally cast steel with 19% Cr, 9% Ni, gave excellent tensile results, if the welding pressure was 10,000 psi. Likewise with steel containing 0.10 C, 0.68 Si, 0.82 Mn, 0.012 P, 0.019 S, 15.5 Cr, 2.02 Mo, 12 Ni, 0.13 Cb excellent results were obtained with sufficient preheat and prolonged welding time. With too short welding time, unwelded (cold) areas are obtained which cannot be eliminated by high pressure due to the low thermal conductivity of the steel.

For crankshafts, bars (30-sq. in. cross section) containing 0.45 C, 0.30 Si, 0.86 Mn, 0.010 P, 0.055 S, 0.71 Cr were welded, annealed, then double heat treated and stress relieved. The weld could not be detected in the structure. Weld specimens had the following properties: yield point 90,000 psi., tensile strength 121,000 psi., elongation in 5 diameters 12%, reduction of area 50%, notch impact value (DVM round notch specimen) 6.5 mkg./cm.^{2}. Bend specimens $^3/_4$ x 1 in. could be bent 180 degrees around a pin 2 in. in diameter. Crankshafts are flash welded of a shaft of Cr-V steel (157,000–171,000 psi, tensile strength) with balance weights of plain carbon steel.

Good results were obtained with flat bars (8- x 1.6-in. cross section) containing 0.30 C, 2.3 Cr, 0.20 V. After welding, the bars were heat treated 20 min. at 1700–1750° F., air-cooled, then 15 min. at 1600–1620° F., oil-quenched, and then 15 min. at 950–970° F., and water-cooled. The 0.2 yield was 164,000 psi.; tensile strength, 178,000 psi.; elongation in 5 diameters, 11%; notch impact value, 2 mkg./cm.^{2}

In the discussion of the steel containing 0.46 C., 1.63 Cr reference was made to defects close to the weld, Figs. 2 and 3. Grain boundary cracks were found about $^1/_{16}$ in. on either side of flash welds in flat bars (4 x 0.79 in. cross section) containing 0.30 C, 2.3 Cr, 0.20 V. The cracks were especially severe with low pressures and long welding times. The macroscopic cracks were shown to occur in the primary grain boundaries associated with bands of inclusions. Similar cracks are found sometimes in plain carbon steel. During the war these cracks appeared in flash-welded tubes $2^1/_4$ in O.D., 0.28-in. wall and locomotive driving rods and coupling rods. The cracks caused a great deal of trouble in technical circles. The cracks start sometimes on one side of a weld and cross to the other side.

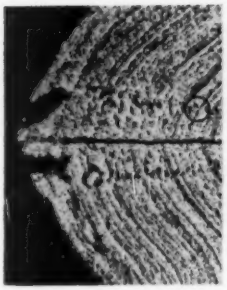

Fig. 2 Cracks in bend specimen of flash-welded tube containing 0.46 C, 1.63 Cr. Oberhoffer etch × 5

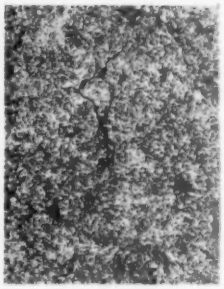

Fig. 3 Magnified view of circle in Fig. 2, etched with nital. × 100

Sometimes magnaflux detects the crack as a fine line.

Examination of the structure shows that the microscopic cracks are associated with the difference in melting point between the steel and the inclusions. Steels with high inclusion content tend to exhibit cracking to a greater degree than steels with low inclusion content. Since the push-up pressure is not distributed uniformly over the cross section, being lowest at the edges, the cracks or microscopic shrinkage cavities are seen most often at the edges. The cracks can be made to disappear by increasing the pressure and shortening the welding time. It is also desirable to maintain the welding current briefly after the beginning of push up, and to permit the weld to cool in the jaws a bit before removal. Too short a welding time, such as used for sheet metal parts, is not satisfactory for heavy sections which require uniform and adequate preheating of the entire cross section to avoid cold welds.

Three other defects may be described. If the steel slips in the jaws during welding, the welds usually contain unwelded areas. Oxide skins appear as grayish flakes in a bend fracture. Radial flakes in the tensile fracture of a flash-welded tube ($1^1/_2$ in. O.D., $^3/_{16}$-in. wall, 0.17 C, 0.47 Si, 0.51 Mn, 0.013 P, 0.023 S, 0.03 Cr, 0.28 Cu, 0.35 Mo) represented brittle areas found to contain large inclusions of mixed manganese oxide and iron silicate.

In the discussion of this paper it was pointed out: (1) that the fine cracks on both sides of the weld might be related to burning, and (2) that the tolerable silicon content for flash welding might be related to the manganese content of the steel.

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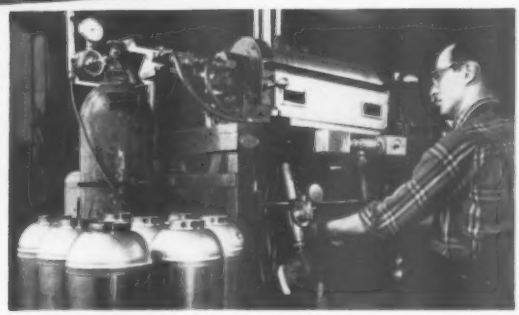

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